

**Will a large-scale expansion of
Arctic shrub extent increase or
decrease permafrost
vulnerability to climate change?**



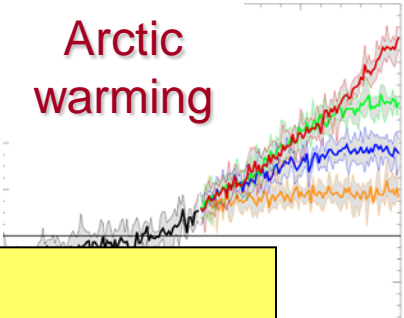
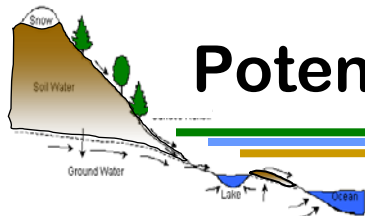
David Lawrence and Sean Swenson
NCAR Earth System Laboratory
Celine Bonfils
Lawrence Livermore National Lab



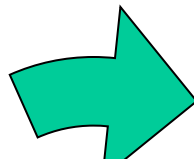
NCAR is sponsored by the National Science Foundation



Potential Arctic terrestrial climate-change feedbacks



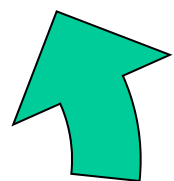
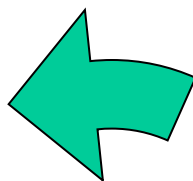
Global warming



Carbon sequester



Shrub growth



Enhanced [nitrogen]

Vegetation

Radiative forcing of complete conversion tundra to shrubland

+8.9W m⁻² (4.2W m⁻² GHG)

(Chapin et al., 2005)

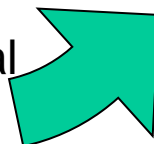
Since 1950, 13% to 20% cover

(Sturm et al., 2005)

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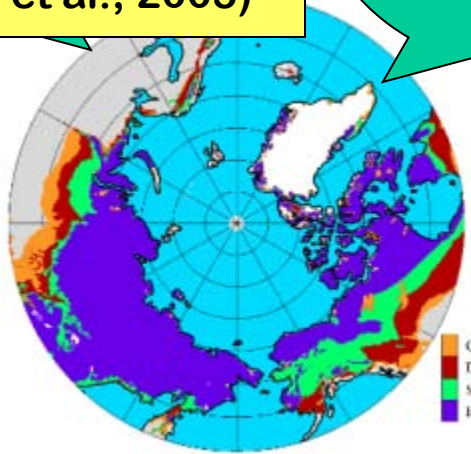
Microbial activity increases



Lakes drain, soil dries



Arctic runoff increases



Shrub cover increasing in Arctic

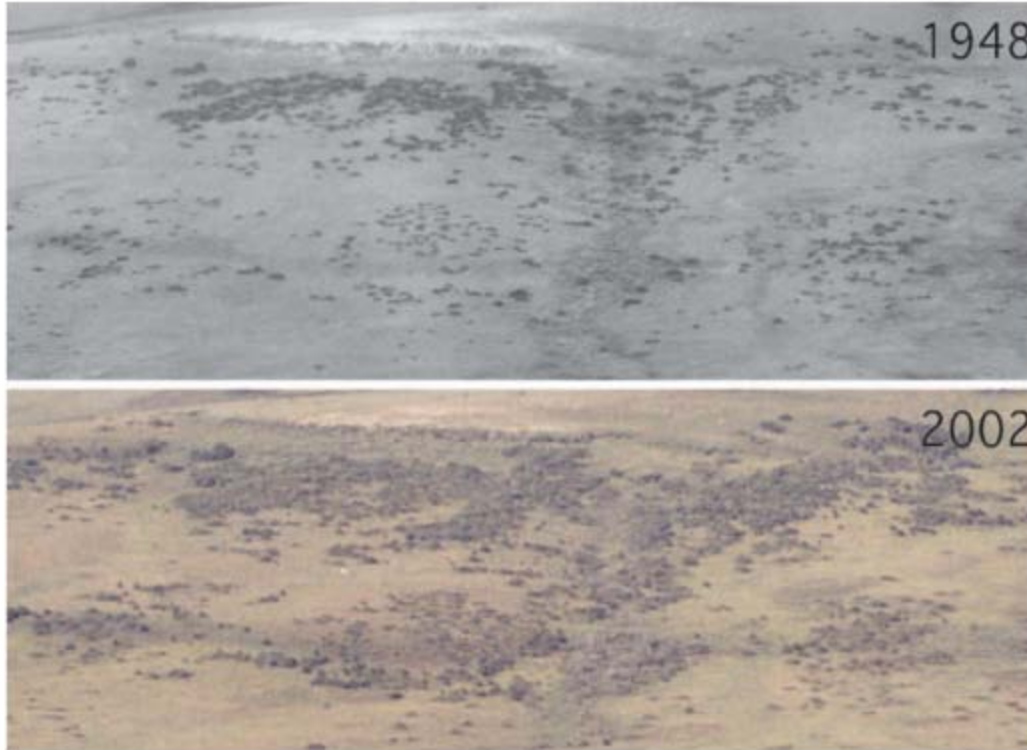
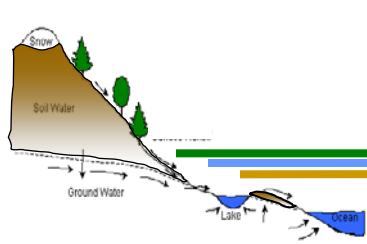
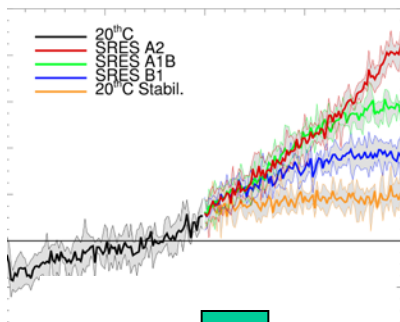
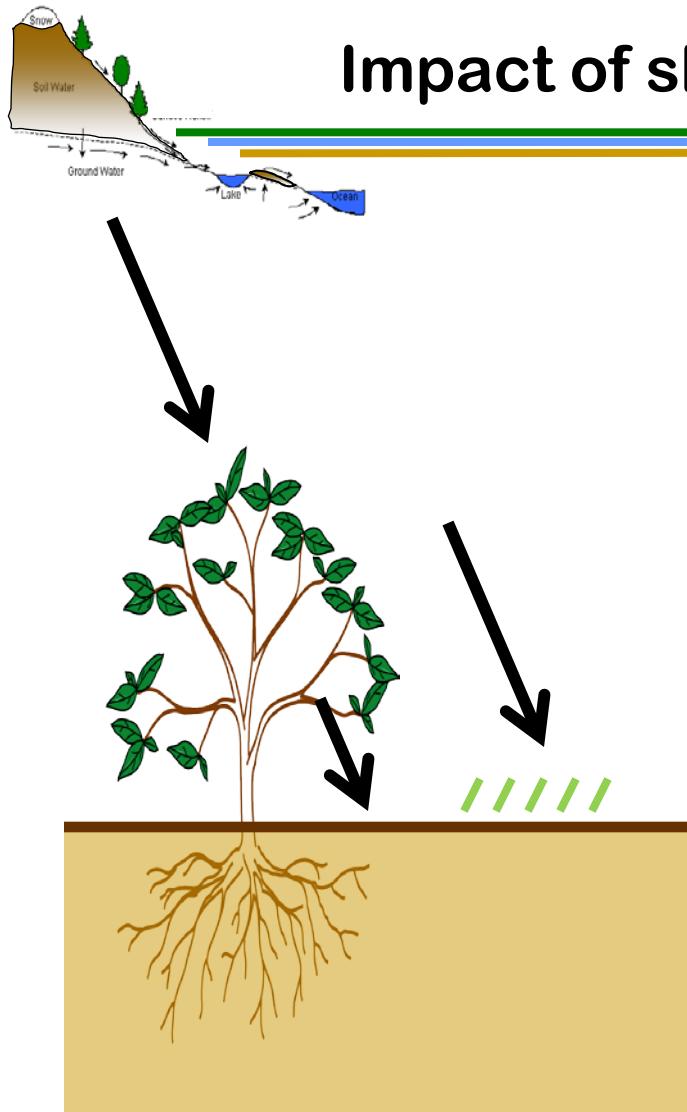


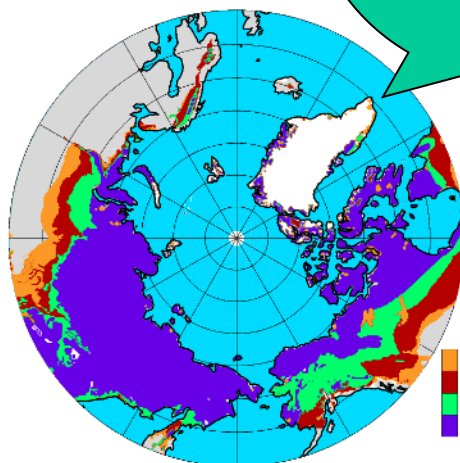
Figure 1. Increasing abundance of shrubs in arctic Alaska. The photographs were taken in 1948 and 2002 at identical locations on the Colville River (68° 57.9' north, 155° 47.4' west). Dark objects are individual shrubs 1 to 2 meters high and several meters in diameter. Similar changes have been detected at more than 200 other locations across arctic Alaska where comparative photographs are available. Photographs: (1948) US Navy, (2002) Ken Tape.

- Shrub cover increasing in N. Alaska at 1.2% per decade since 1950, 15% to 20% cover (Sturm et al. 2001)
- Similar increases seen in Canada
- No studies for Siberia, but satellite NDVI data indicates that Siberia is getting 'greener' and one explanation for this is increasing shrub cover

Impact of shrubs on climate and permafrost



Permafrost
warms and
thaws



Microbial
activity
increases

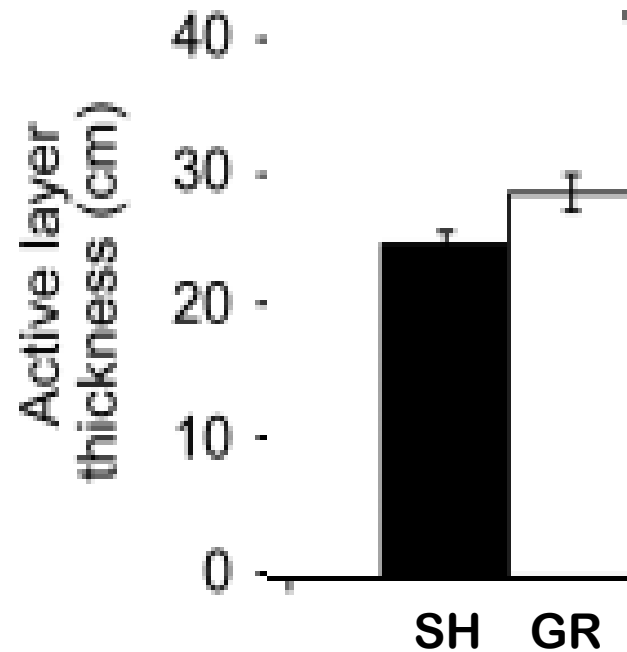
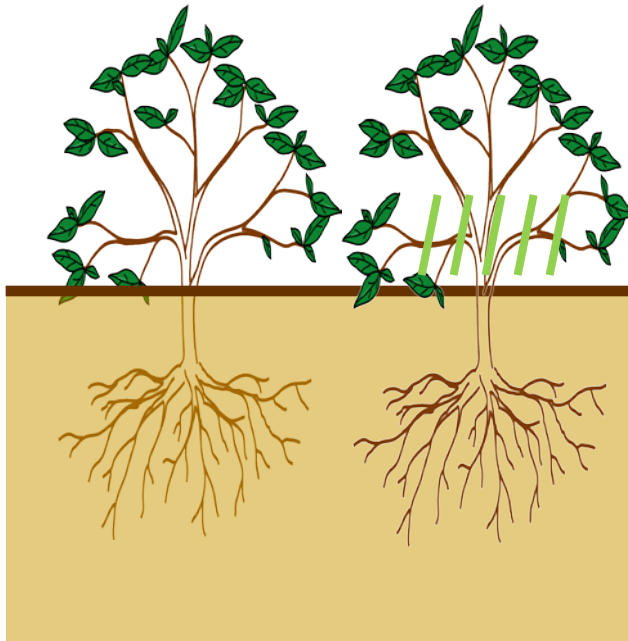
Shrub
growth

Carbon
sequester

Enhanced
[nitrogen]

Shrub expansion may reduce summer permafrost thaw in Siberian tundra

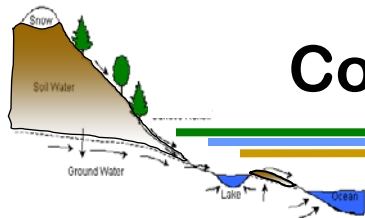
D. BLOK*, M. M. P. D. HEIJMANS*, G. SCHAEPMAN-STRUB*†, A. V. KONONOV‡, T. C. MAXIMOV‡ and F. BERENDSE*



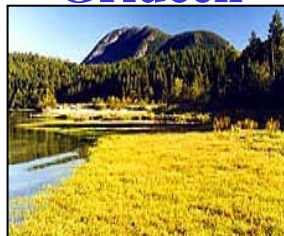
“These results suggest that the expected expansion of deciduous shrubs in the Arctic region, triggered by climate warming, may reduce summer permafrost thaw.”

Evaluate this hypothesis using CAM4/CLM4

Community Land Model subgrid tiling structure



Gridcell



Landunit



Glacier



Wetland



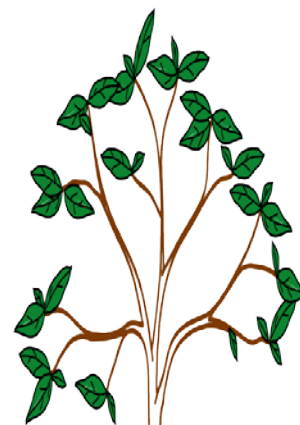
Vegetated



Lake



Urban

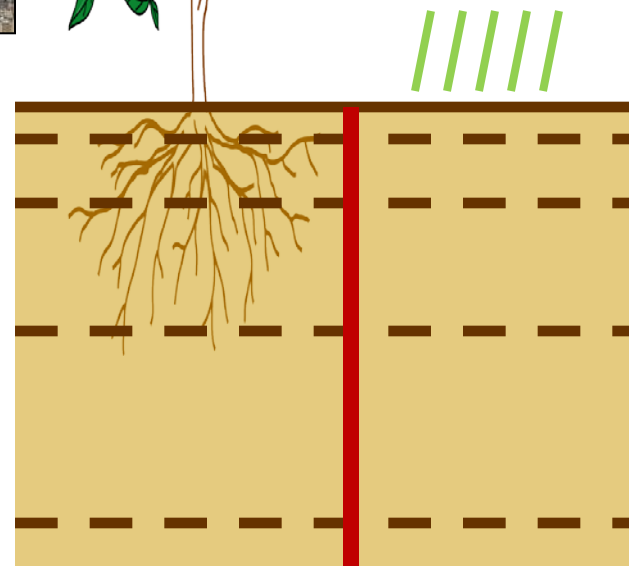
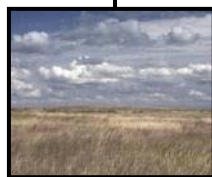
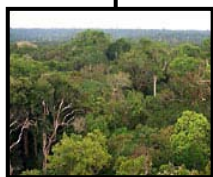


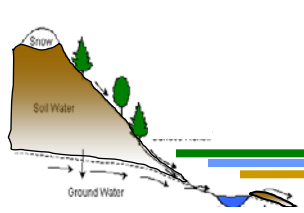
Columns



Soil Type 1

PFTs

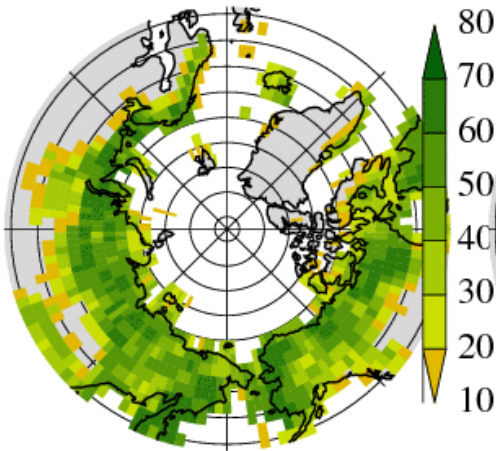




Experimental Design

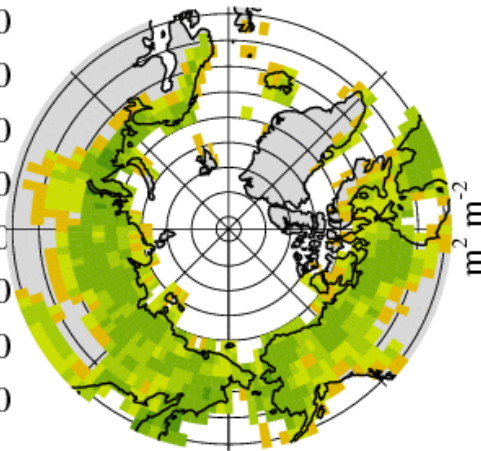
SB_LOW

Arctic C3 Grass

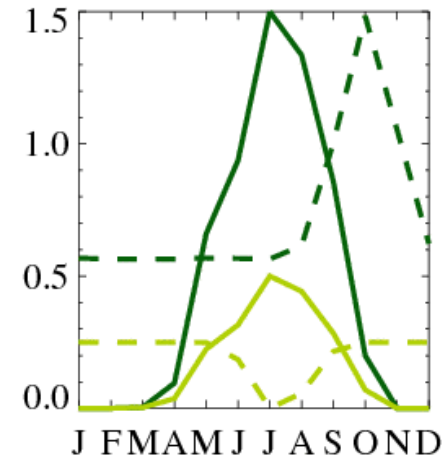


SB_HIGH

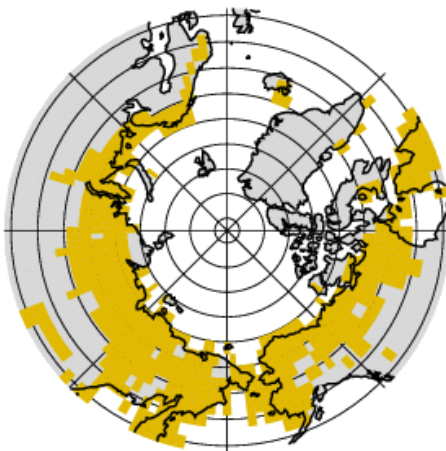
Arctic C3 Grass



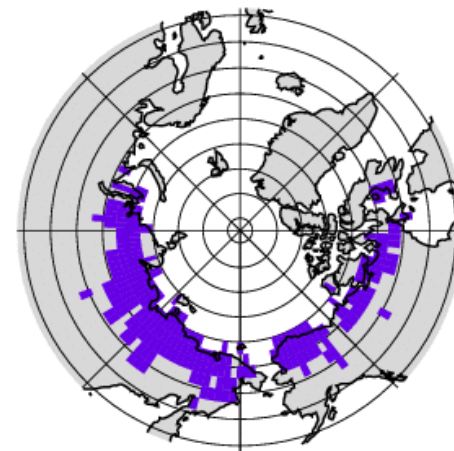
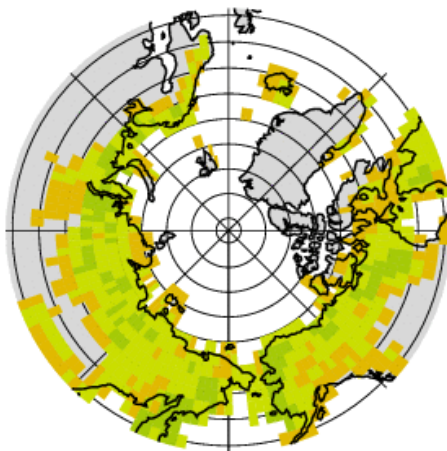
- Arctic C3 Grass
- Boreal Shrub
- LAI
- SAI

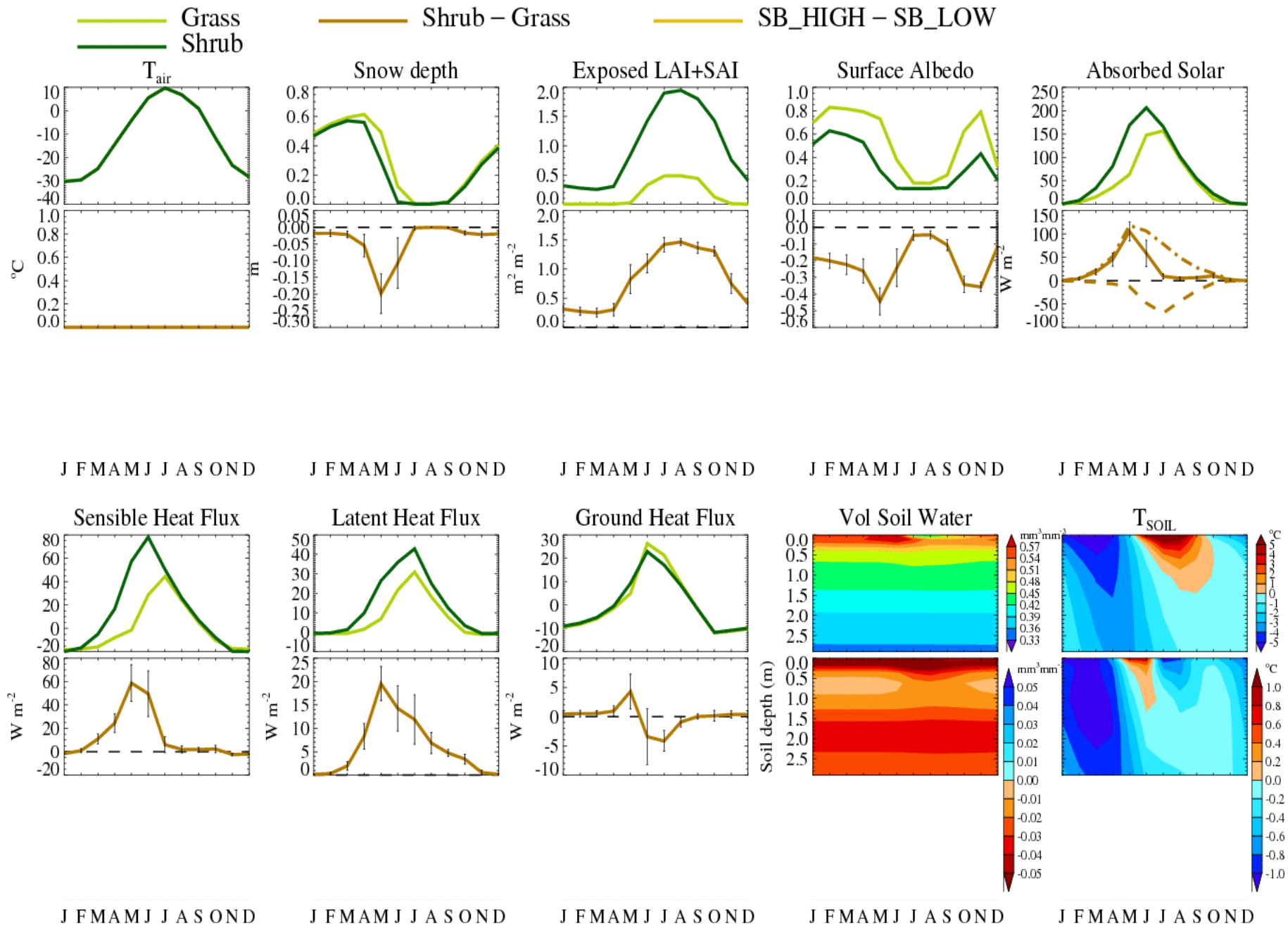


Boreal Shrub

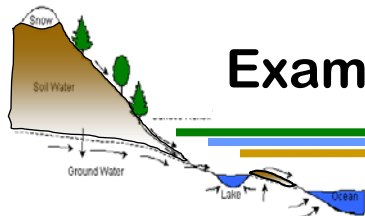


Boreal Shrub

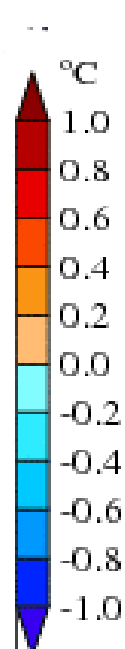
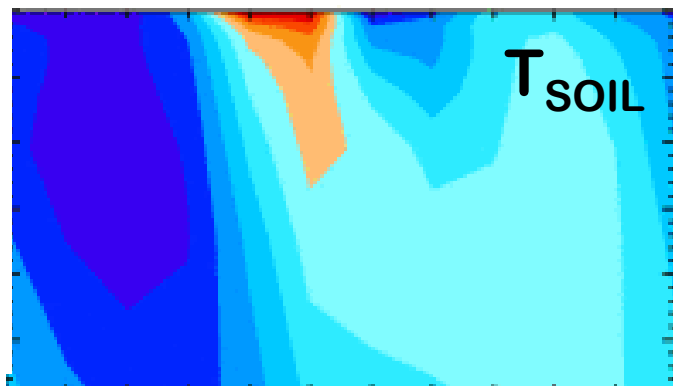
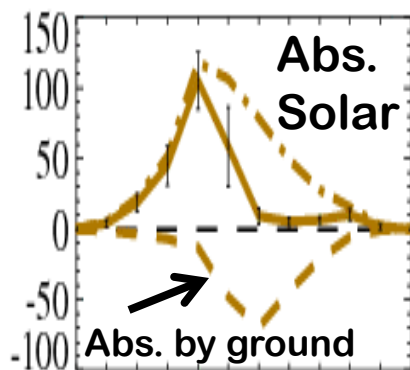




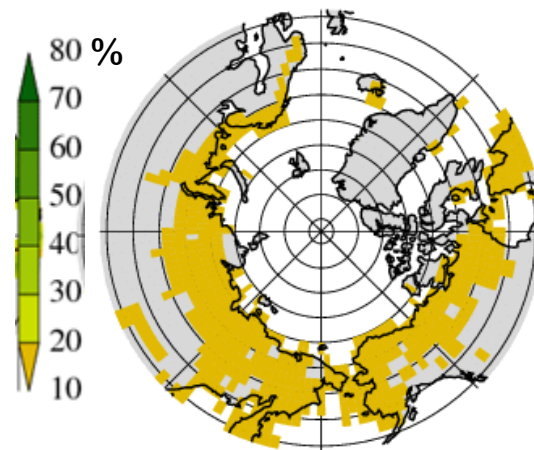
Examining impact of shrubs on permafrost using CAM4/CLM4



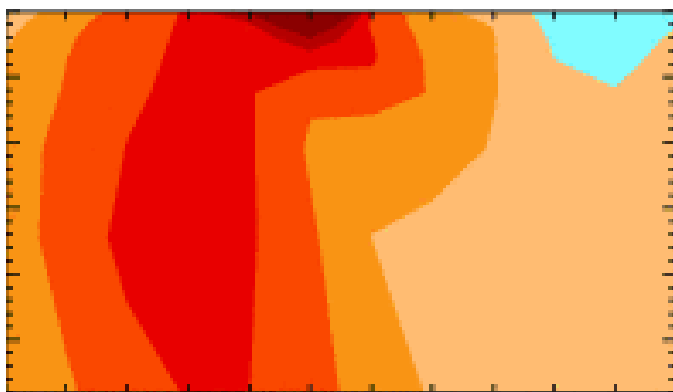
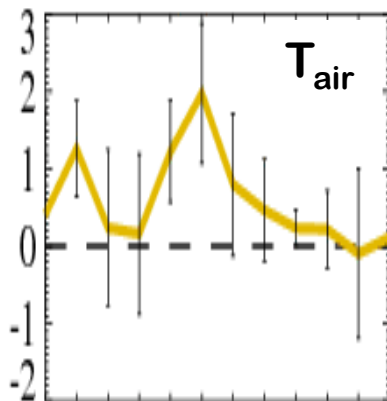
SB_LOW: Shrub – Grass



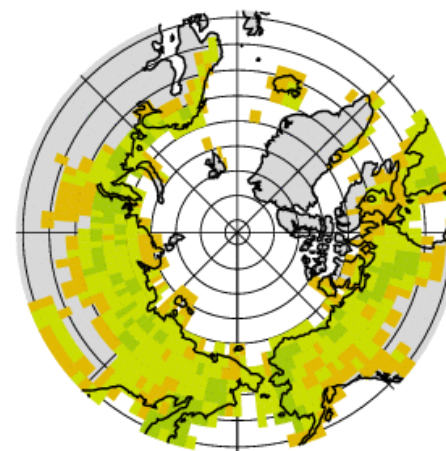
SB_LOW Boreal Shrub



SB_HIGH – SB_LOW: Grid cell mean

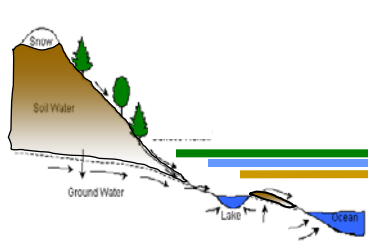


SB_HIGH Boreal Shrub

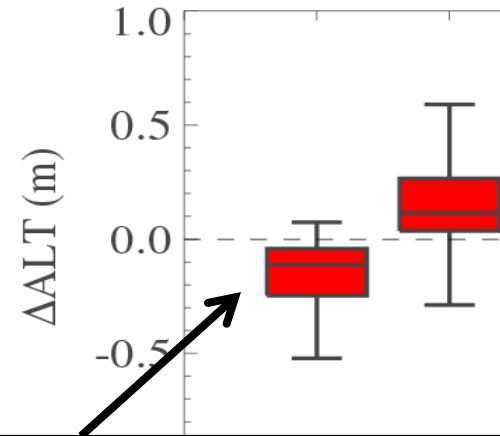
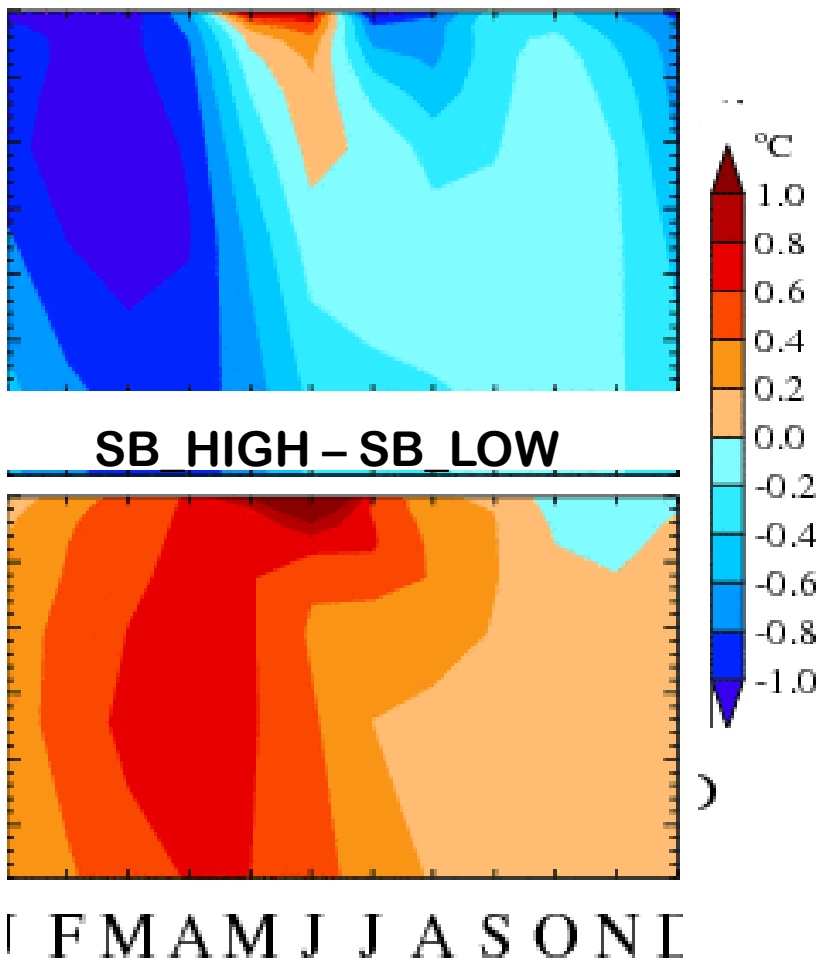


J F M A M J J A S O N D | F M A M J J A S O N D

Impact of shrubs on permafrost



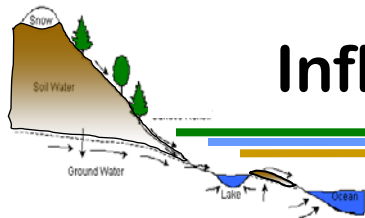
Shrub - Grass



CLM can replicate results from field manipulation study (Blok et al. 2010)

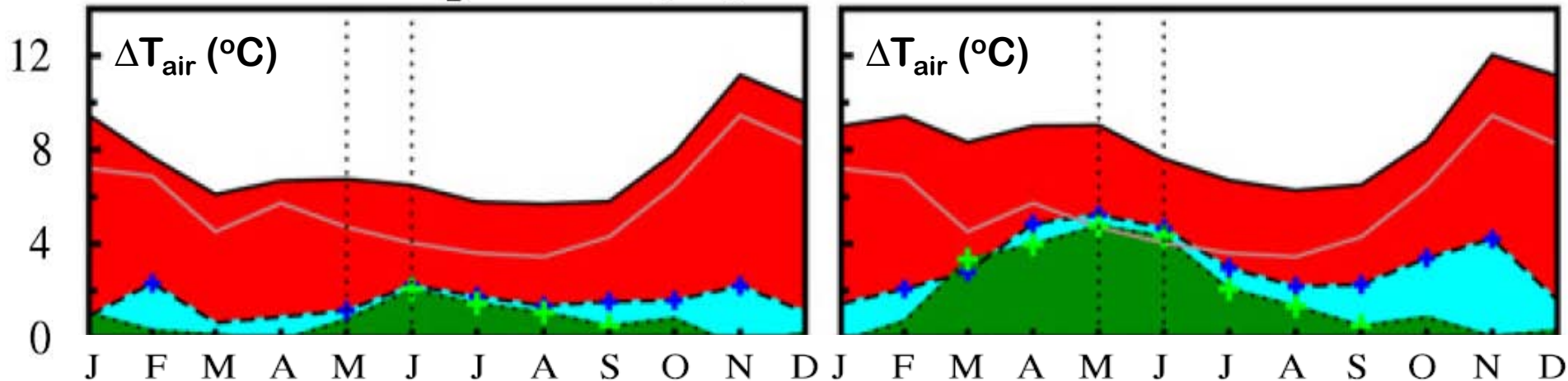
But, if climate feedbacks are considered, ground actually gets warmer, suggesting that **shrub area expansion may increase rather than decrease permafrost vulnerability.**

Influence of shrub height and sea ice feedbacks



Short shrubs (0.5m)

Tall shrubs (2m)

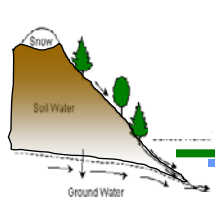


Effect of adding shrubs (FO)

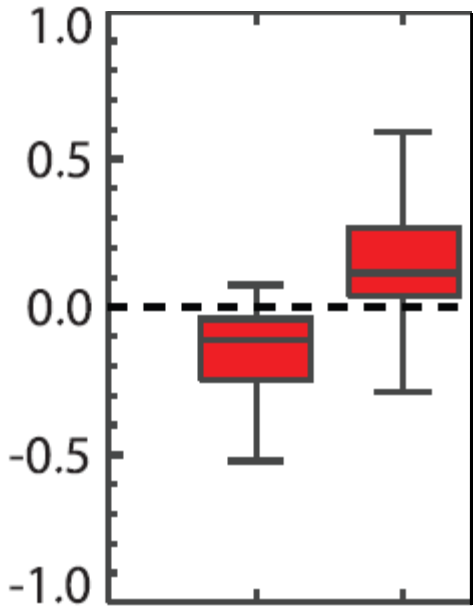
Added effect from IO

Added effect from $2\times\text{CO}_2$

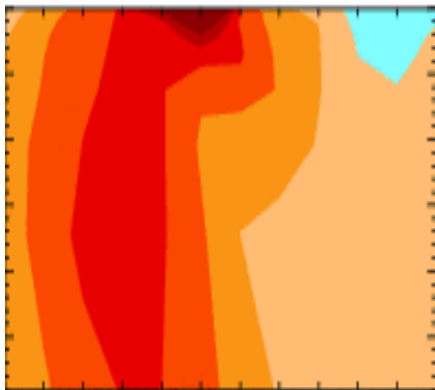
Impact of snow redistribution



w/o snow redist

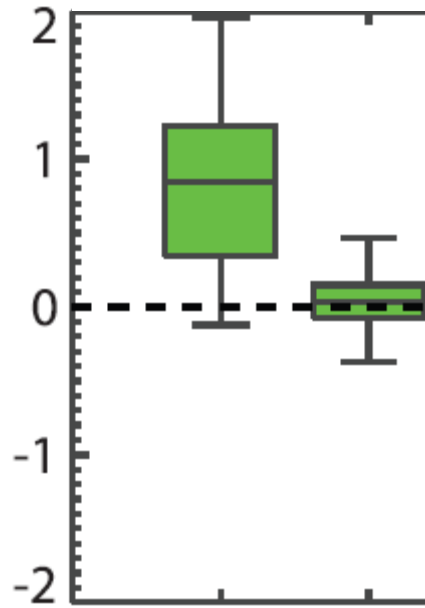


$\Delta T_{air} = 0.59 \text{ } ^\circ\text{C}$

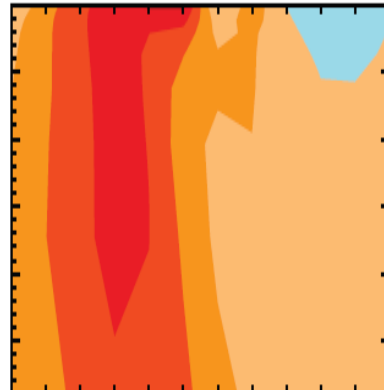


J F M A M J J A S O N D

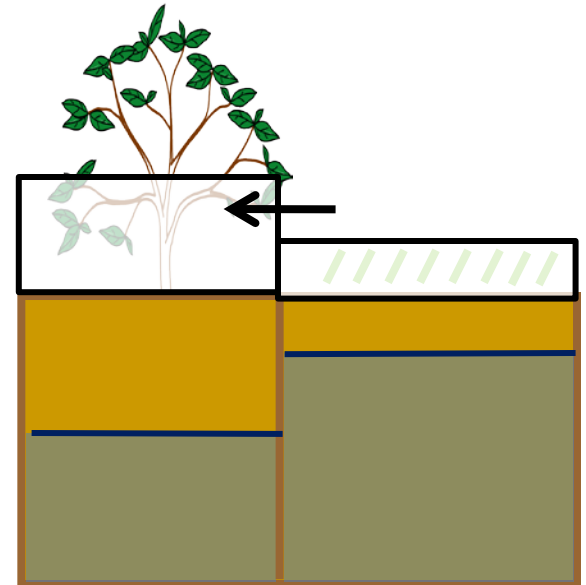
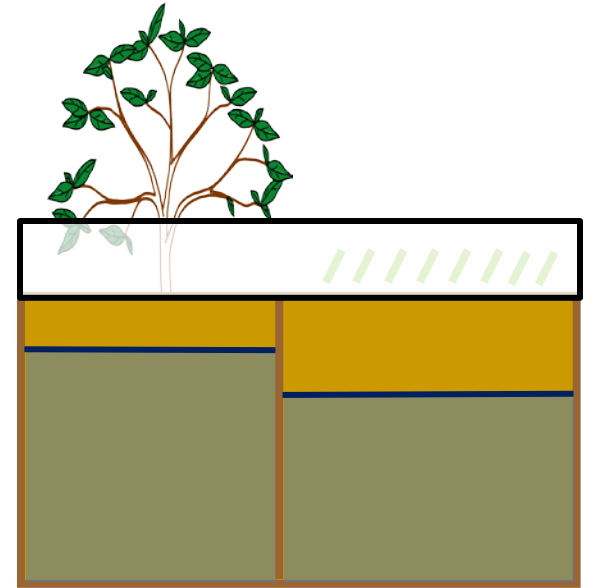
w/ snow redist

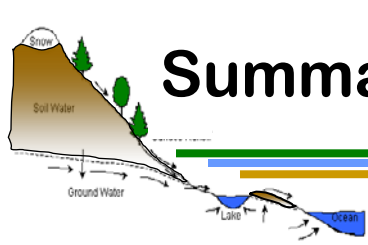


$\Delta T_{air} = 0.46 \text{ } ^\circ\text{C}$



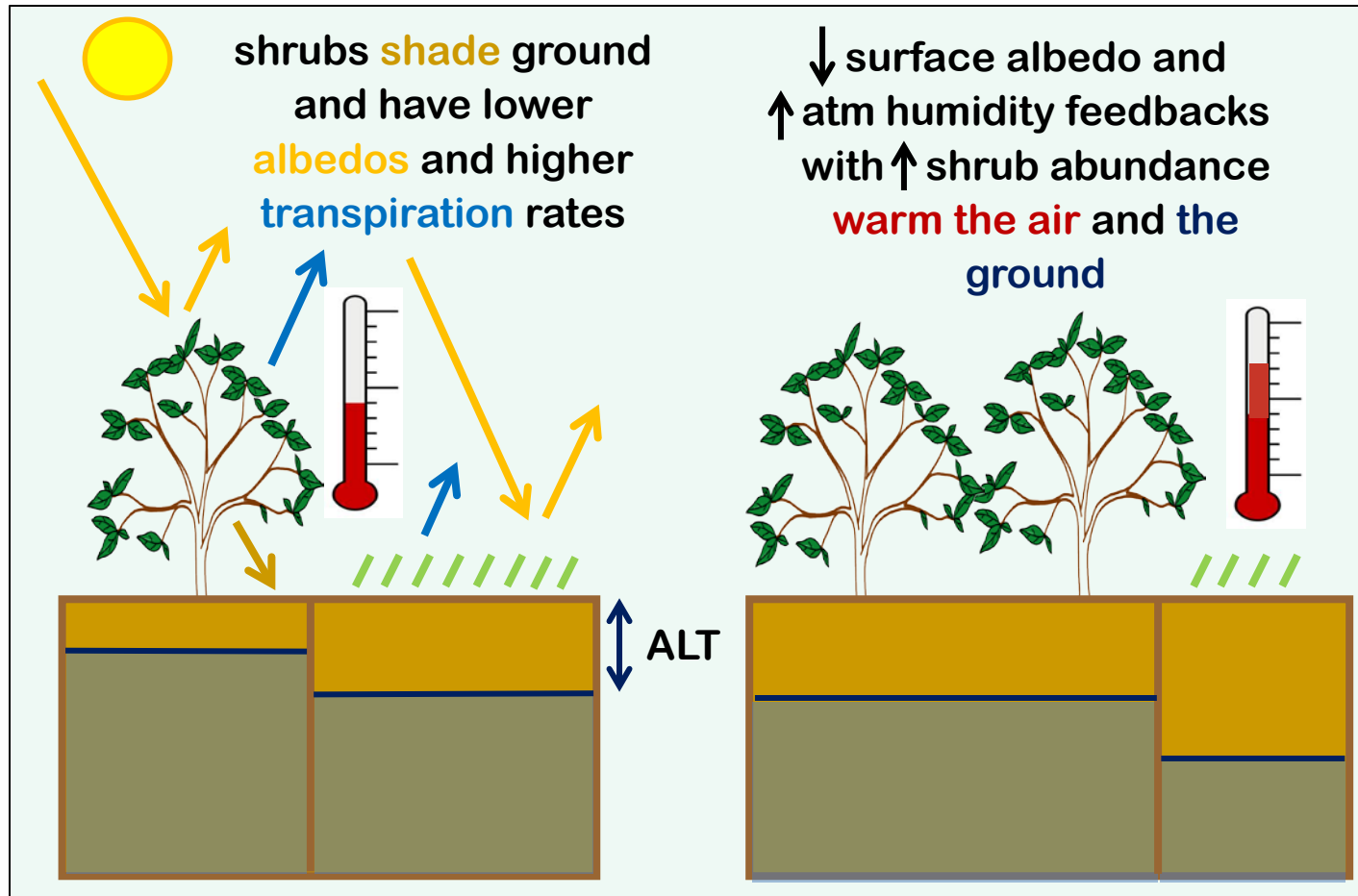
J F M A M J J A S O N D





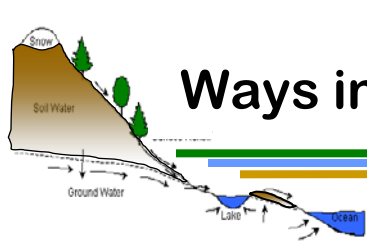
Summary (Lawrence and Swenson, ERL, 2011; Bonfils et al., ERL, 2012)

Will expanding Arctic shrub cover decrease permafrost vulnerability to climate change?



A. Not necessarily. Depends on whether the direct local cooling or the indirect climate warming dominates. Our results indicate that **shrub cover expansion may increase rather than decrease permafrost vulnerability** to climate change. Shrub height, snow redistribution, and sea ice feedbacks modify the response.





Ways in which shrubs can affect above and belowground climate

Shrubs compared to tundra

- absorb more solar
- earlier snowmelt
- shade the ground
- deeper snow drifts (insulation)
- higher transpiration

(Sturm et al. 2005)

Radiative forcing of complete conversion tundra to shrubland

+8.9W m⁻² (4.2W m⁻² GHG)

(Chapin et al., 2005)



Photo by M. Sturm