Arctic Basin Land Surface Soil Temperature and Moisture Algorithm Development and Validation for Biophysical Monitoring

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Research Questions and Objectives

- Can ecosystem models driven by global satellite algorithms capture stand to regional scale Arctic carbon cycle dynamics?

- To answer this question we need to obtain accurate retrievals of near surface soil temperature and moisture parameters that are:

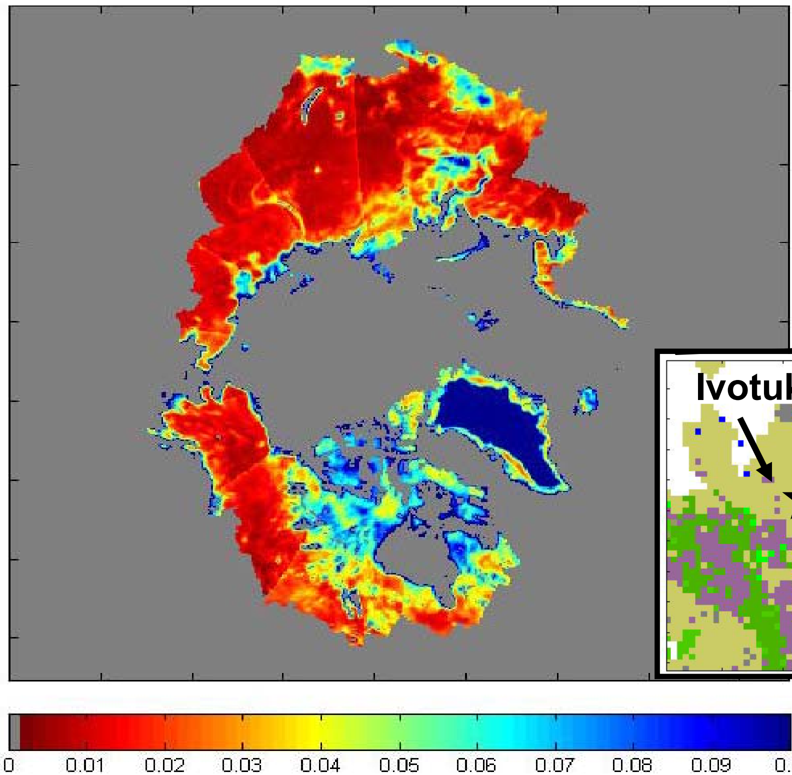
  Robust across land cover and temporally changing surface conditions encountered at high latitudes, such as flooding and vegetation phenology

  Have retrieval accuracy within an acceptable level of error given the carbon model parameter sensitivities

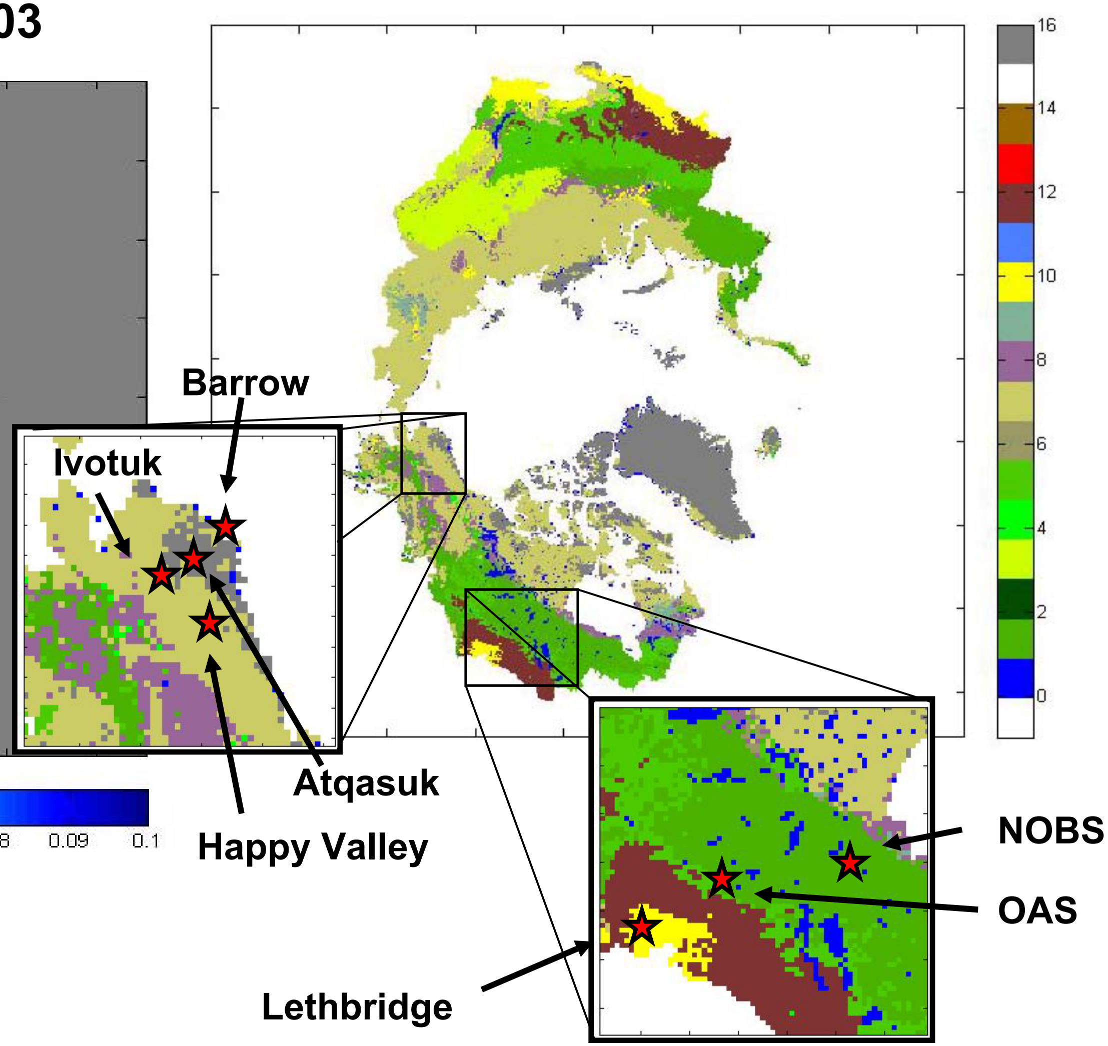
Photo courtesy F.A. Heinsch

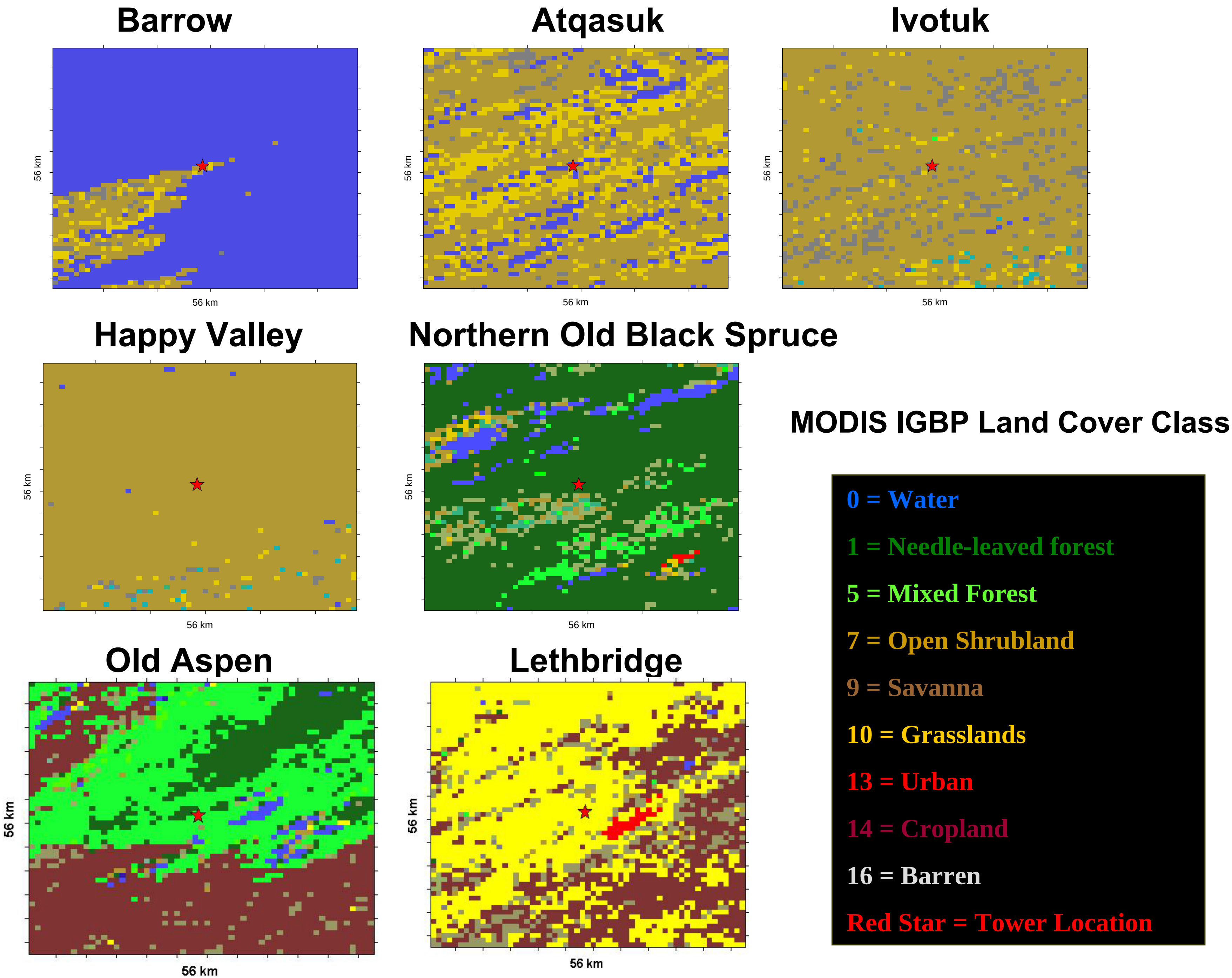
Arctic and Boreal Study Sites

ζ 6.9 GHz for July 15, 2003

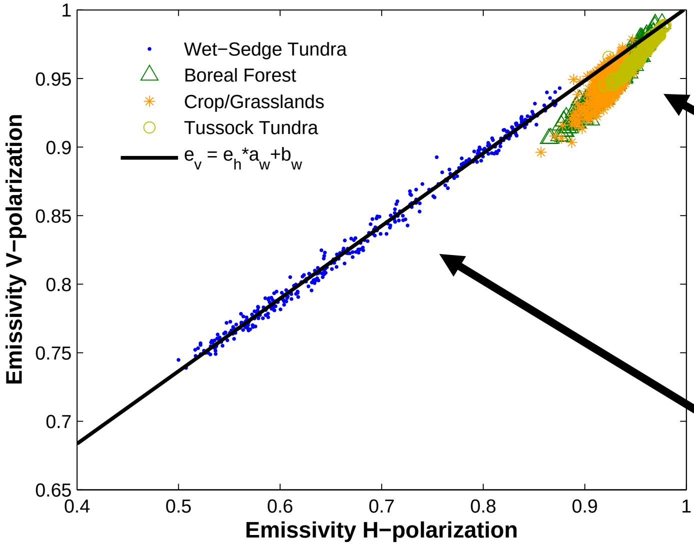


MODIS IGBP Land cover




Barrow
56 km
56 km
Atqasuk
56 km
56 km
Ivotuk
56 km
56 km
Happy Valley
56 km
56 km
Northern Old Black Spruce
56 km
56 km
Old Aspen
56 km
56 km
Lethbridge
56 km
56 km
MODIS IGBP Land Cover Class
0 = Water
1 = Needle-leaved forest
5 = Mixed Forest
7 = Open Shrubland
9 = Savanna
10 = Grasslands
13 = Urban
14 = Cropland
16 = Barren
Red Star = Tower Location

AMSR-E Polarization Signatures of High Latitude Land Cover



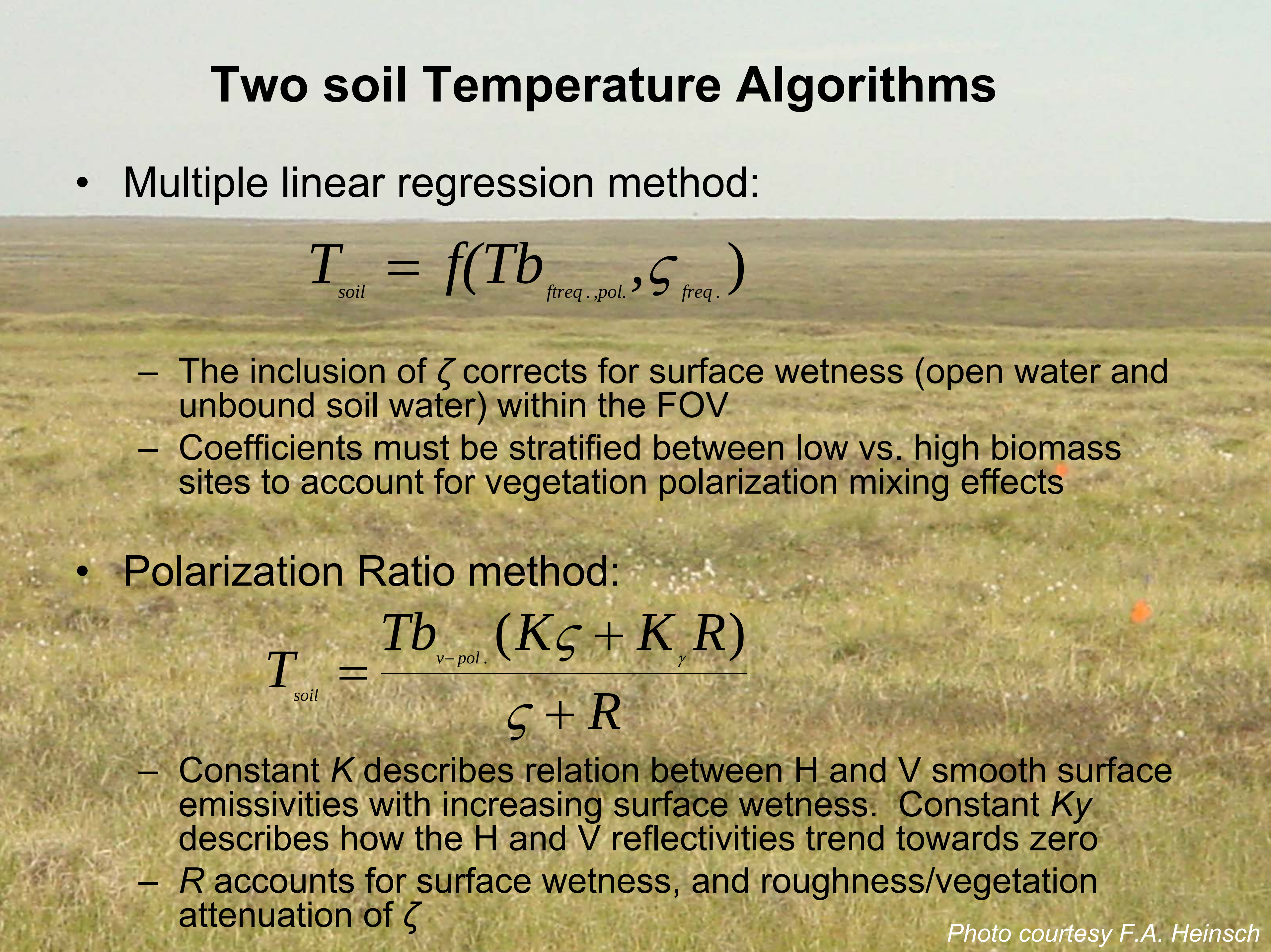
89 GHz

Forest
Tussock Tundra
Grasslands

Wet Sedge Tundra

Polarization Difference Ratio $\varsigma = \dfrac{Tb_v - Tb_h}{Tb_v + Tb_h} = \dfrac{e_v - e_h}{e_v + e_h}$ where $Tb_v = e_{pol.} T_s$

- By normalizing out the surface temperature, ζ is sensitive to dielectric and scattering properties of the surface which influence the emissivity
- Surface wetness increases ζ and reduces the emissivity
- Vegetation/roughness tends to decrease ζ and increase the emissivity by mixing the *h* and *v* polarized emission, approaching a slope of 1.



Two soil Temperature Algorithms

- Multiple linear regression method:

$$T_{soil} = f(Tb_{ftreq.,pol.}, \varsigma_{freq.})$$

  - The inclusion of ζ corrects for surface wetness (open water and unbound soil water) within the FOV
  - Coefficients must be stratified between low vs. high biomass sites to account for vegetation polarization mixing effects

- Polarization Ratio method:

$$T_{soil} = \frac{Tb_{v-pol.}(K\varsigma + K_{\gamma} R)}{\varsigma + R}$$

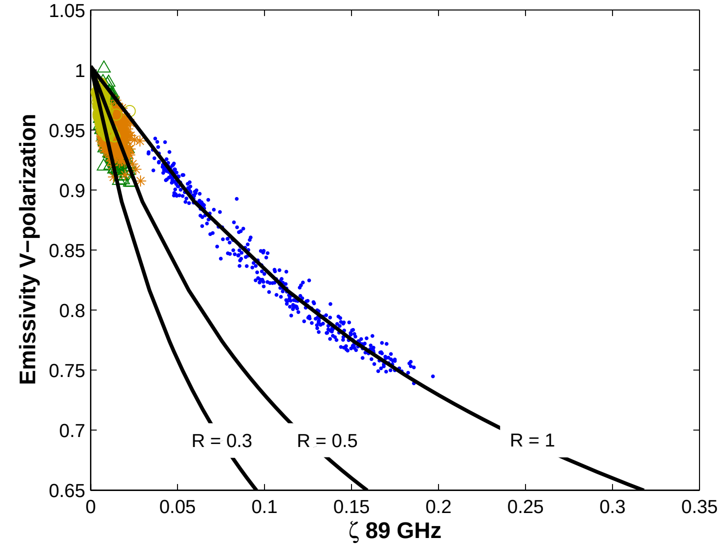
  - Constant *K* describes relation between H and V smooth surface emissivities with increasing surface wetness. Constant *Ky* describes how the H and V reflectivities trend towards zero
  - *R* accounts for surface wetness, and roughness/vegetation attenuation of ζ

Photo courtesy F.A. Heinsch

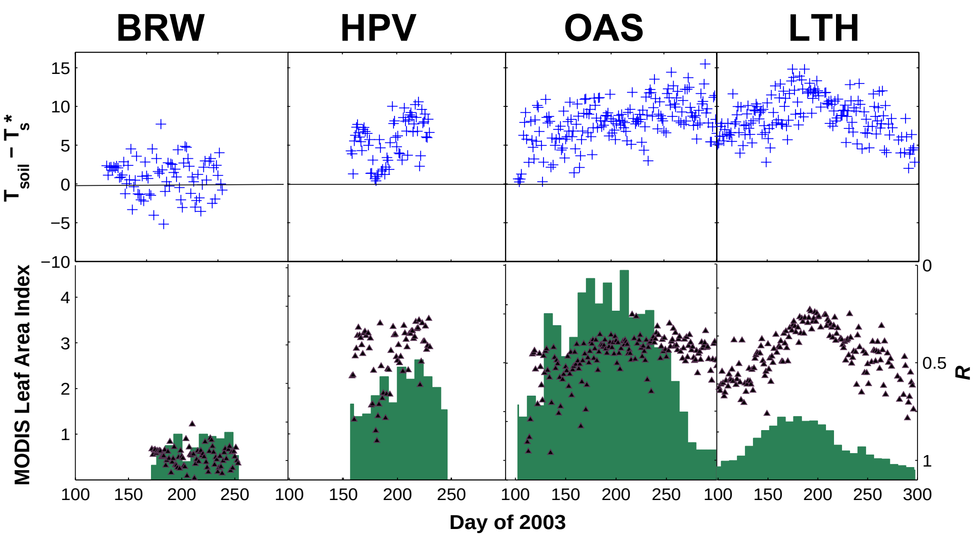
The Vegetation/Roughness Factor (*R*)

$$\varsigma = \varsigma_w * R$$

- Describes the reduction in ζ in reference to a smooth surface $\boldsymbol{\zeta_w}$ whose variability is solely due to **incidence angle** and changes in the **surface dielectric**
- Includes exponential and frequency-dependent terms
- **Varies between 0 (high veg.) and unity (little or no veg.)** under thawed conditions



Ts Residual (assuming R=1)[1] is related to LAI



- Related to **vegetation seasonal phenology**
- Assumed to have **lower frequency temporal variability** than $\boldsymbol{\zeta_w}$
- Can be estimated accurately by comparing slope between h-v emissivities vs. slope expected for a smooth, wet surface
- Regional estimation requires other means

[1]Identical to the method developed by Fily *et. al., Rem. Sens. Environ.* 2003

Site Soil Temperature Retrieval

a) **Polarization Ratio Method**

	R^2	RMSE	MR	slope
Barrow	0.6	2.37	0.12	0.9
Atqasuk	0.69	1.66	-0.15	0.92
Ivotuk	0.64	1.91	-0.26	1.12
Happy Valley	0.44	2	-0.31	1.3
NOBS	0.49	3.12	-0.83	0.82
OAS	0.72	2.36	-0.33	0.98
Lethbridge	0.78	2.42	-0.33	0.95

b) **Multiple Regression Method**

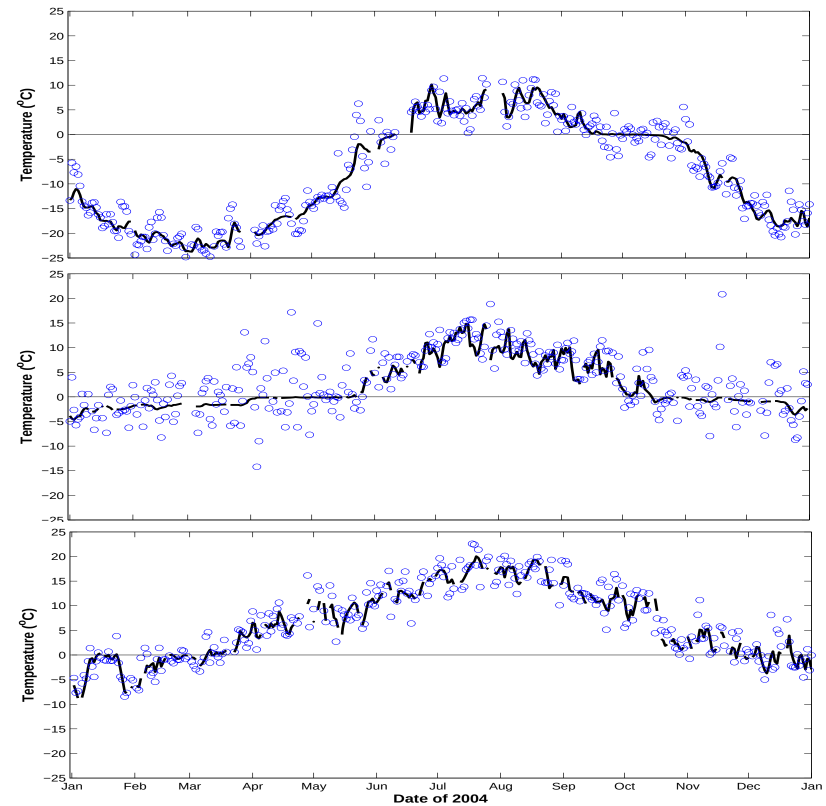
	R^2	RMSE	MR	slope
Barrow	0.62	2.17	0.87	0.67
Atqasuk	0.72	1.57	0.66	0.66
Ivotuk	0.69	1.37	0.44	0.59
Happy Valley	0.52	1.17	-0.26	0.75
NOBS	0.43	2.97	-1.07	0.55
OAS	0.68	2.44	-0.19	0.9
Lethbridge	0.71	2.63	-0.53	0.67

Polarization Ratio Method (89GHz)

Barrow

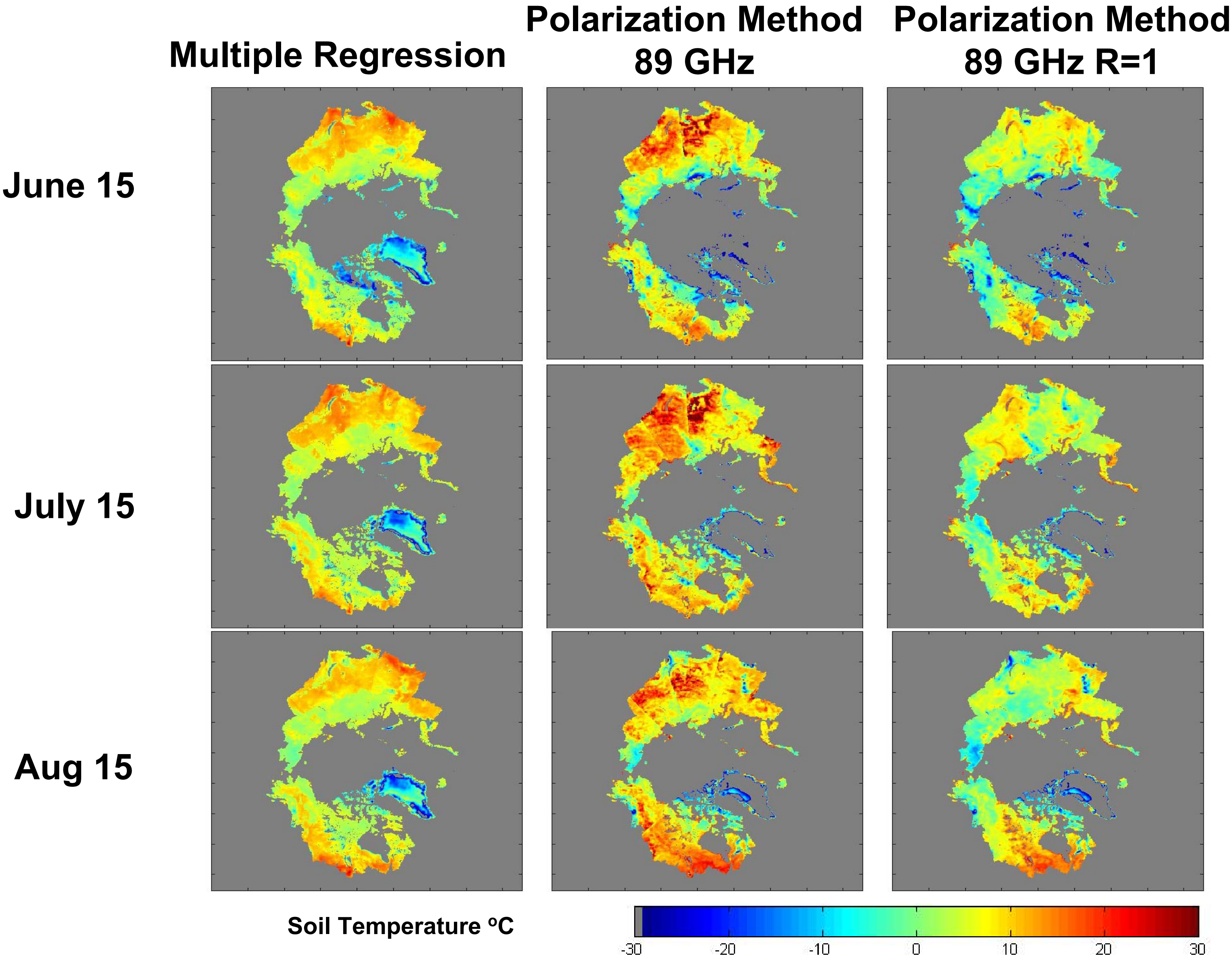
NOBS

Lethbridge

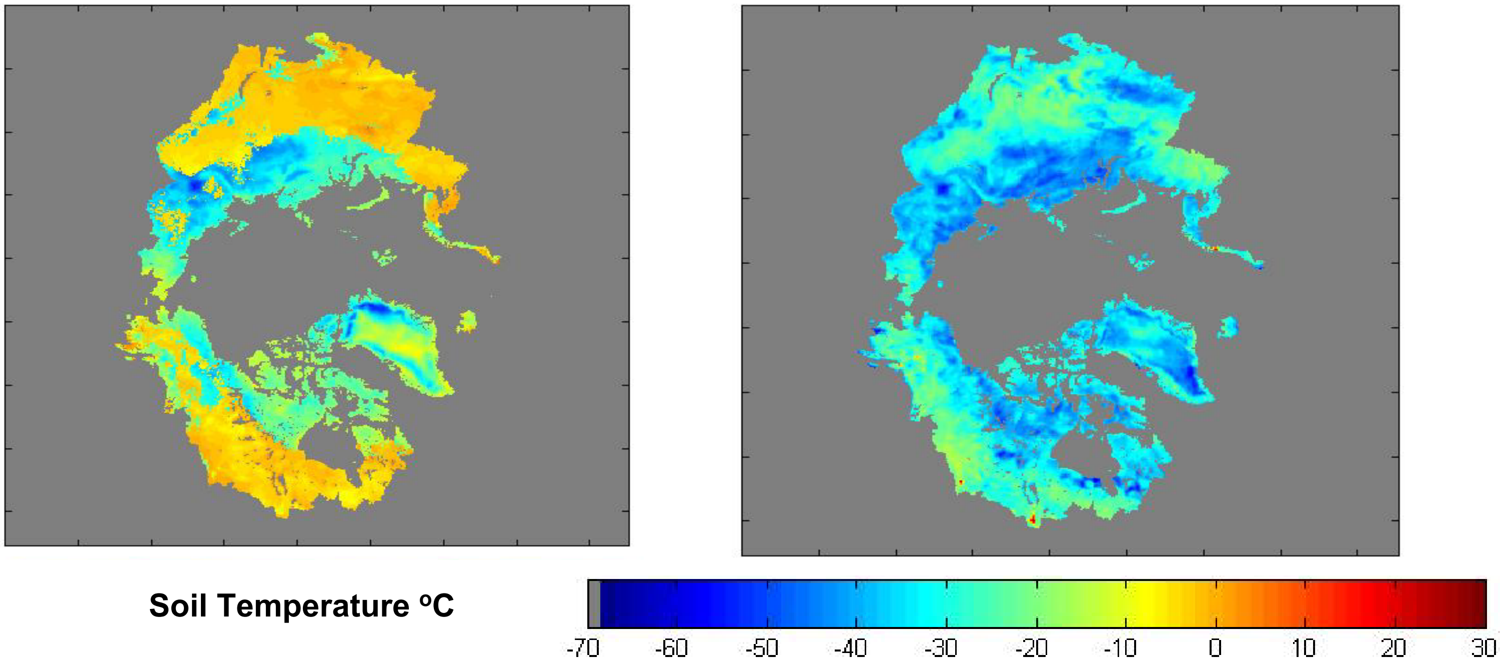


Soil temperature retrieval statistics overall across sites and frozen and thawed seasons for the polarization ratio method were RMSE = 3.37 K; R^2 = 0.87 and RMSE = 3.61 K; R^2 = 0.81 for the regression method.

Source: Jones L.A., Kimball, J.S. et al. *TGARS* 2006 (In-review)


Multiple Regression
Polarization Method
89 GHz
Polarization Method
89 GHz R=1
June 15
July 15
Aug 15
Soil Temperature °C
-30
-20
-10
0
10
20
30

Incorporation of a snow depth term reduces winter retrieval land cover patchiness



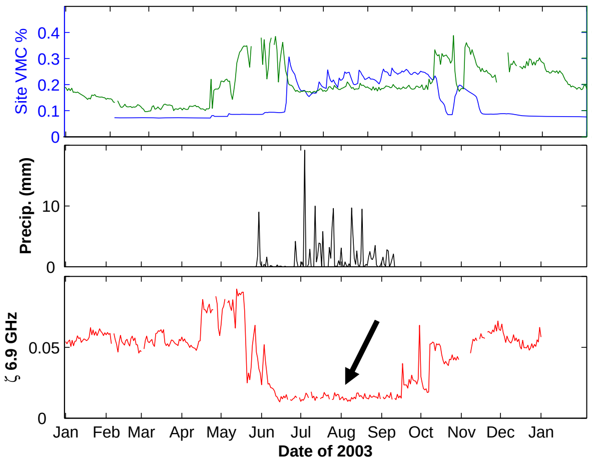
Multiple Regression with coefficients separated by Boreal vs. Arctic land covers

Multiple Regression with a term sensitive to snow depth (normalized difference between 18.7 GHz and 36.5 GHz H bands)

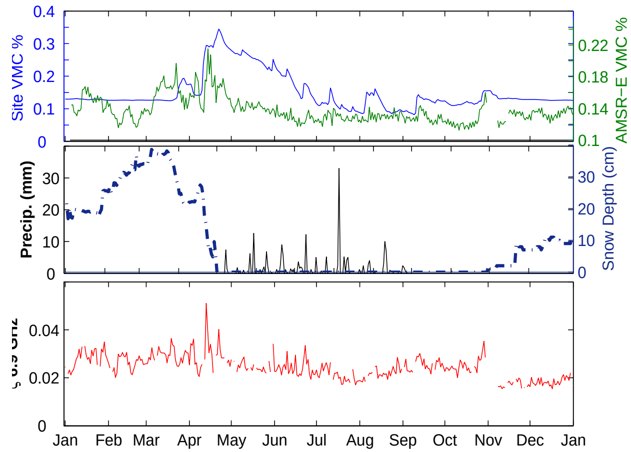
Jan. 15, 2003

Surface wetness Signatures correspond to site hydrologic variables

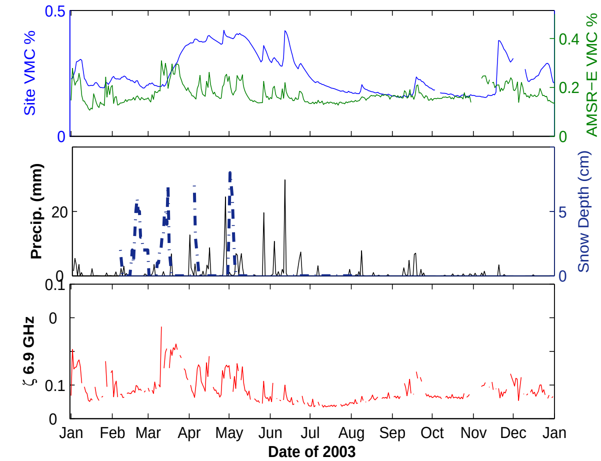
Happy Valley/Sagwon Hill (Tussock Tundra)



Old Aspen (OAS) (Decid. Boreal Forest)

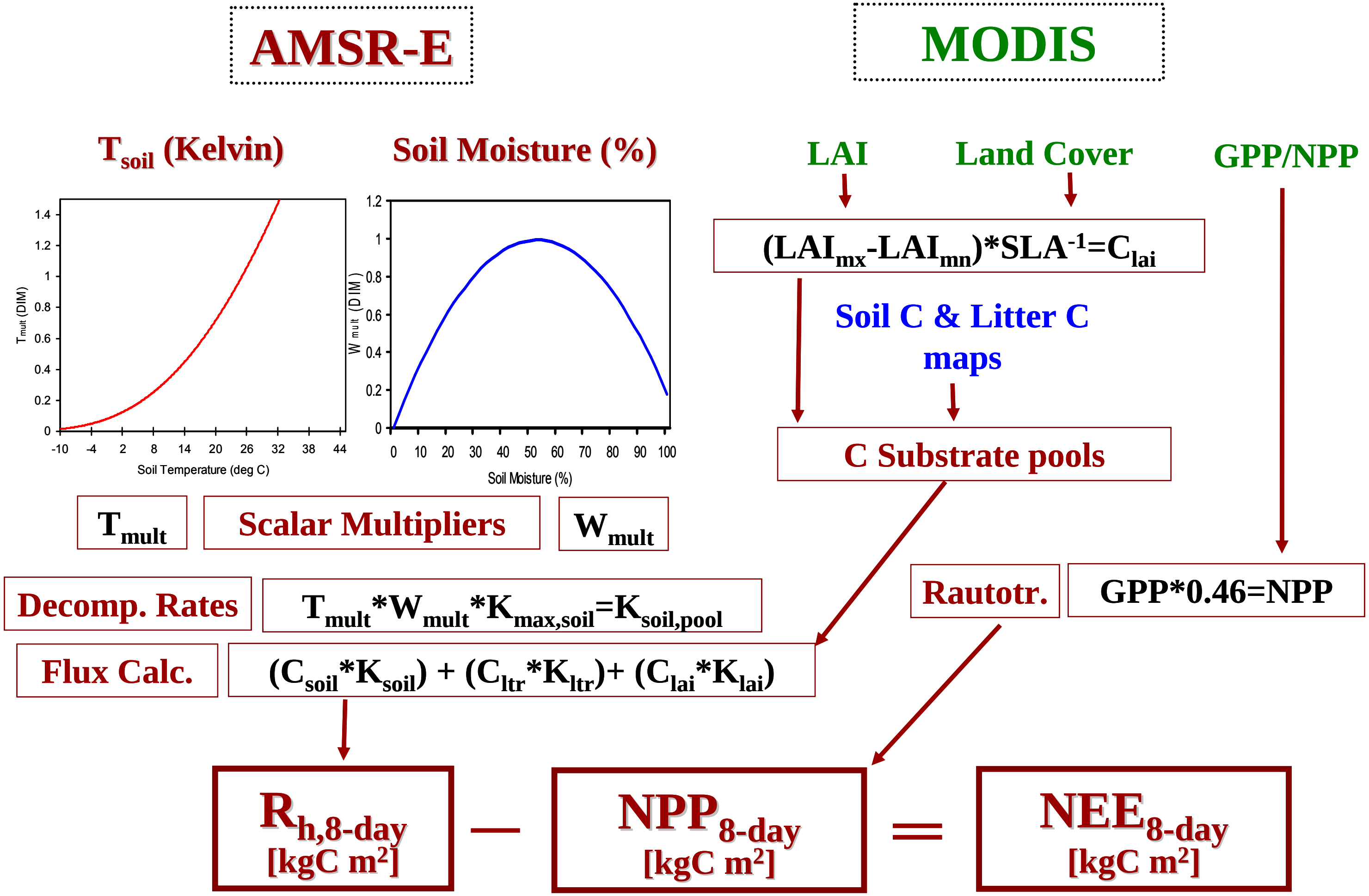


Lethbridge (Grasslands)

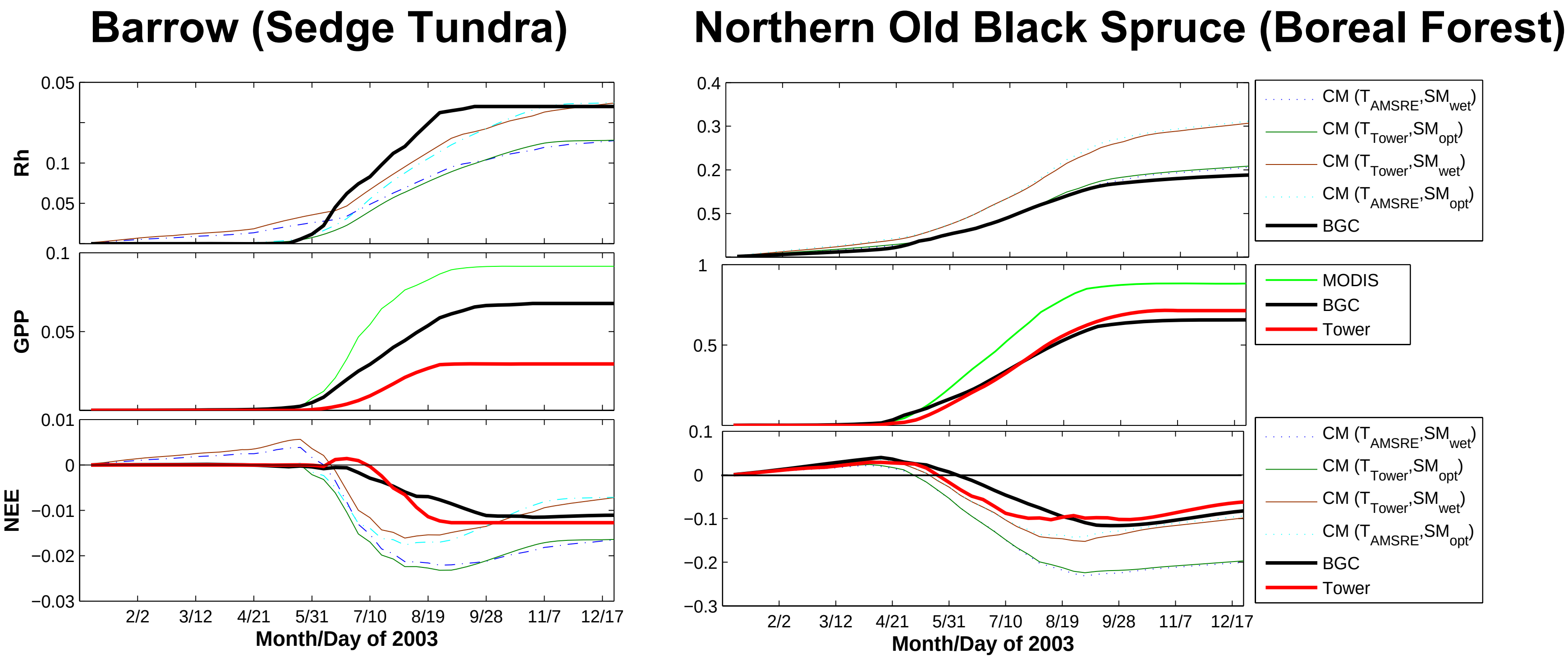


- ζ at 6.9 GHz corresponds to site precipitation and soil moisture time series
- The AMSR-E L3 soil moisture does not add dynamic variability above that shown by ζ and differs in magnitude from the site soil moisture
- Tussock tundra exhibits a low polarization ratio despite high volumetric moisture content
- Potentially caused by water bound to moss surfaces, and organic litter

Carbon Model Structure



Sensitivity of Annual Net CO_2 Exchange Estimates [kg C m^{-2} y^{-1}] to AMSR-E Soil Temperature



•The carbon model is more sensitive to the soil temperature parameter than the soil moisture parameter because of the exponential vs. convex parabolic respective curves used to drive the model multipliers

•Estimates of annual accumulated carbon driven by AMSR-E soil temperature (RMSE = 2.17 and 2.97 K respectively) introduce <1.6% relative error when compared to model estimates derived by tower meteorology (Note: Y-axis scale is one order of magnitude greater for NOBS)

Current Findings

- Soil temperature can be accurately retrieved from AMSR-E by employing land cover information
- AMSR-E soil temperature introduces relatively little error in annual model estimates of net CO_2 exchange when compared against flux tower meteorology
- The AMSR-E driven Carbon Model captures biome differences and seasonality of net CO_2 exchange when compared against flux tower estimates and stand level process model simulations
- The relativity low site-level correspondence with the AMSR-E Level 3 soil moisture product, time series correspondence with the 6.9 GHz polarization ratio (ζ) indicates the potential for algorithm improvements, and suggests the need for a validation strategy over natural land cover employing coarse resolution hydrologic information

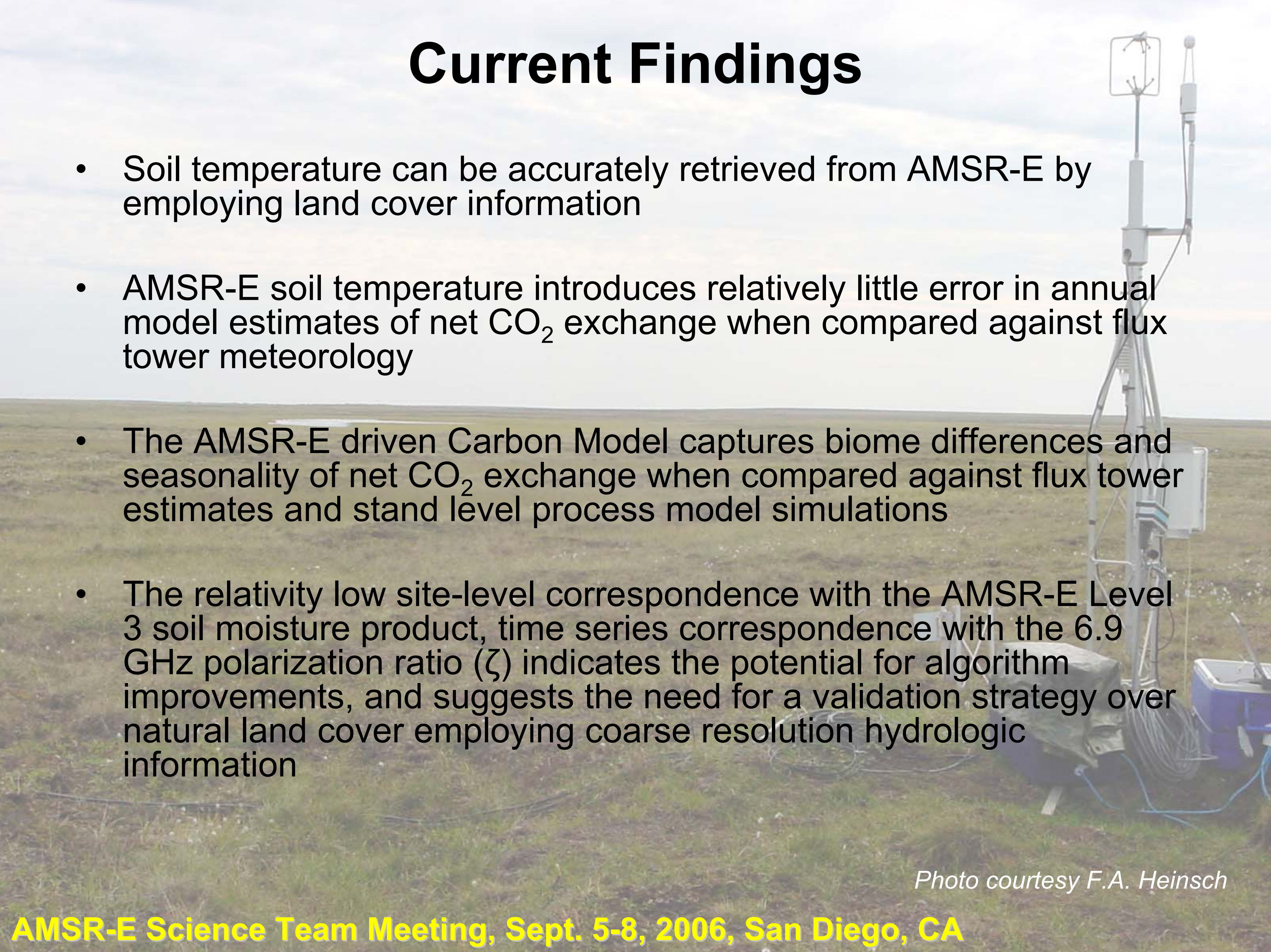


Photo courtesy F.A. Heinsch

Next Steps

- Explore new options for regional estimation of vegetation/roughness effects such as constrained forward inversion or frequency-polarization indices.
- Refinement and validation of the surface wetness algorithm
- Regional application of temperature and surface wetness algorithms
- Determine sensitivity of the Carbon Model to all driving parameters in addition to AMSR-E soil temperature and moisture
- Regional application of the Carbon Model
- Continue updating site and satellite datasets and process model simulations

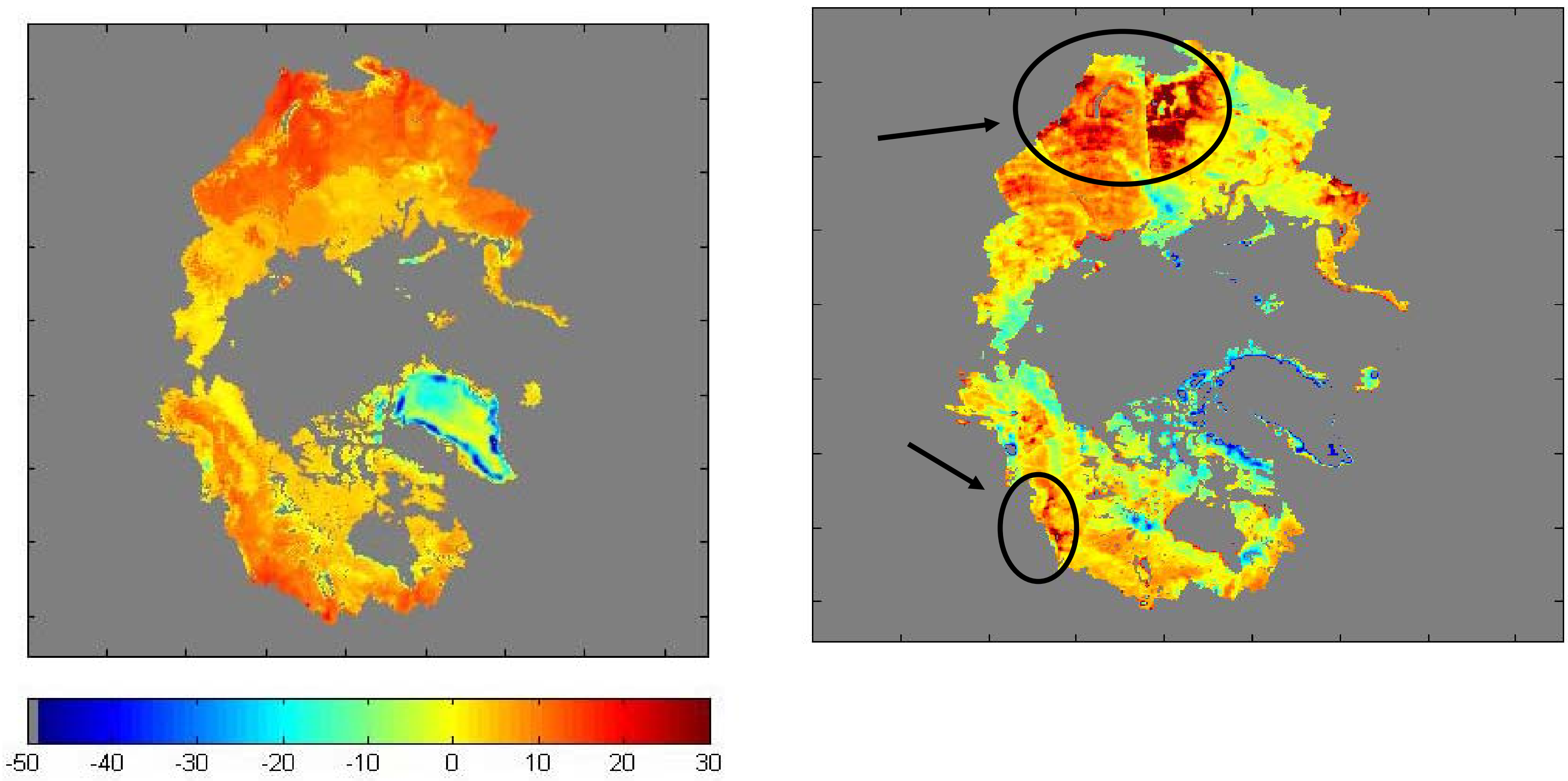
Photo courtesy F.A. Heinsch

Questions?

The End

Surface Roughness Effects

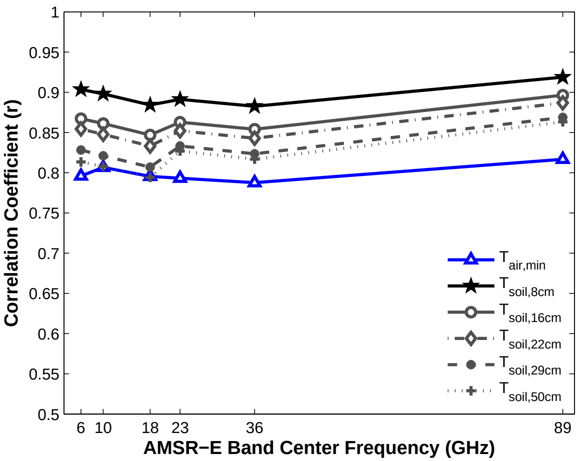
Multiple Regression Method **Polarization Ratio Method**



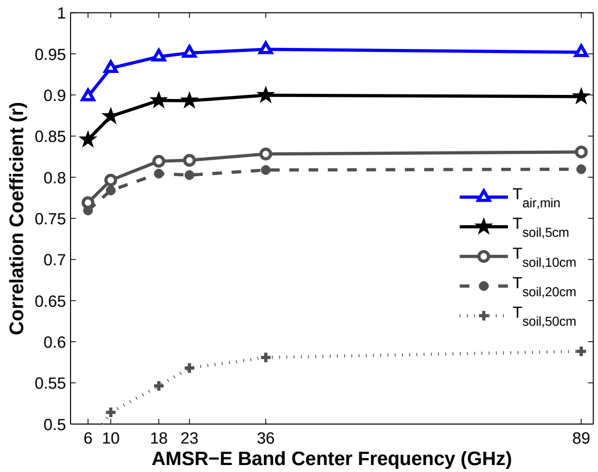
July 15, 2003 Soil temperature (° Celsius)

Although the Polarization Ratio method produced more accurate site retrieval, difficulty in estimating the *R* parameter reduce the algorithms current applicability to regional application

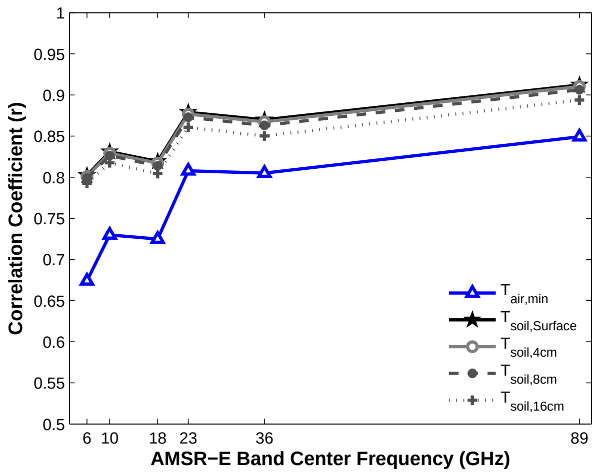
Linear correlation between AMSR-E brightness temperature and soil/air temperature profiles



Happy Valley
(Tussock Tundra)



Northern Old Black Spruce
(Boreal Evergreen Forest)



Lethbridge
(Grassland)