Soil Temperature Damping Depth in Boreal Plain Forest Stands and Clear Cuts: Comparison of Measured Depths versus Predicted based upon SWAT Algorithms

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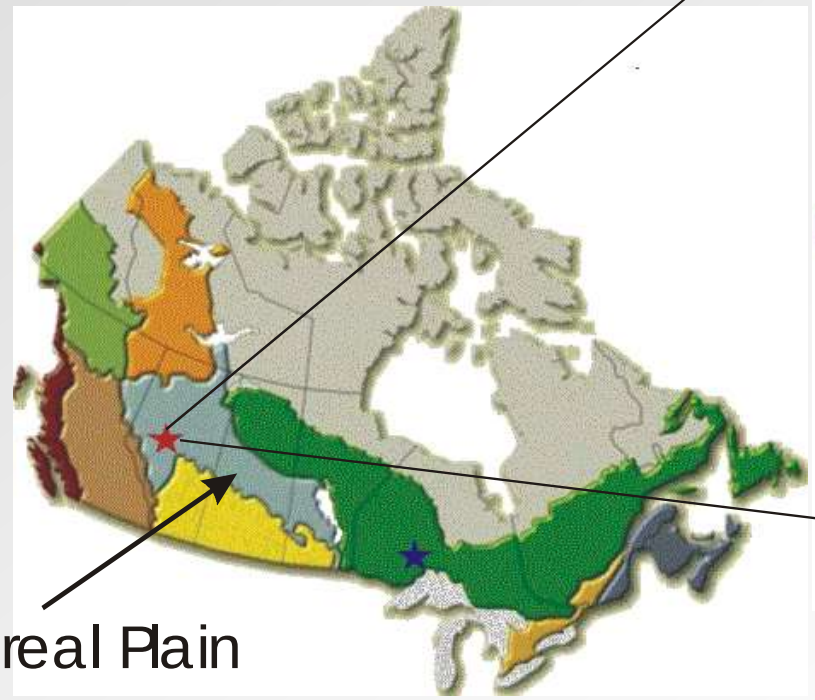
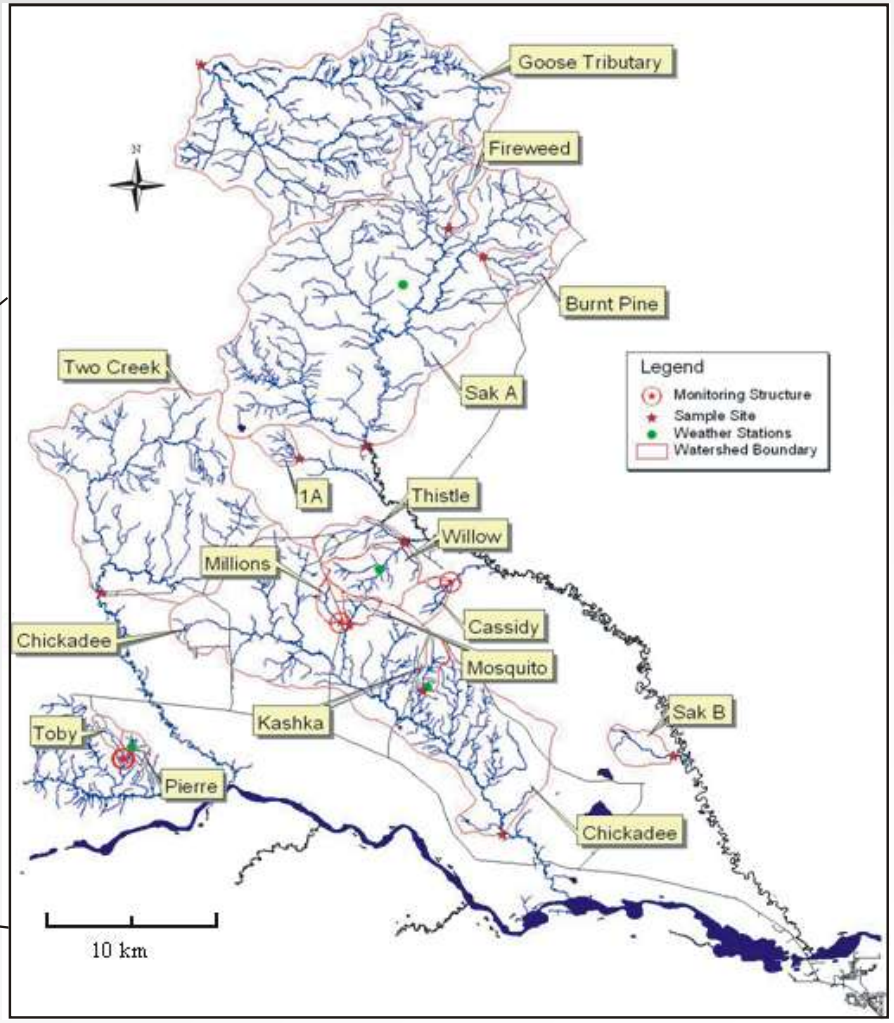
FORWARD Project: Boreal Plain Watersheds

- 14 long term forest watersheds
  - 6 reference, 3 burned, 5 harvested
  - 2 Large Scale (129 & 247 km^2)
  - 12 Small Scale (2.6 to 15.6 km^2)
- 6 additional MPB watersheds





Boreal Plain forest

- Upland dominated by lodgepole pine, trembling aspen, white spruce and balsam poplar
- Lowlands dominated by black spruce and tamarack

- 325 to 625 mm ppt annually
- 1/4 as snow, spring melt
- Sporadic storms May to Sept.
- Predominantly deep clay till soils (luvisols)
- Wetlands and organic soils in low areas (histosols)

Watershed Harvest – Winter of 2003/2004

Soil Temperature and Water Content Monitoring

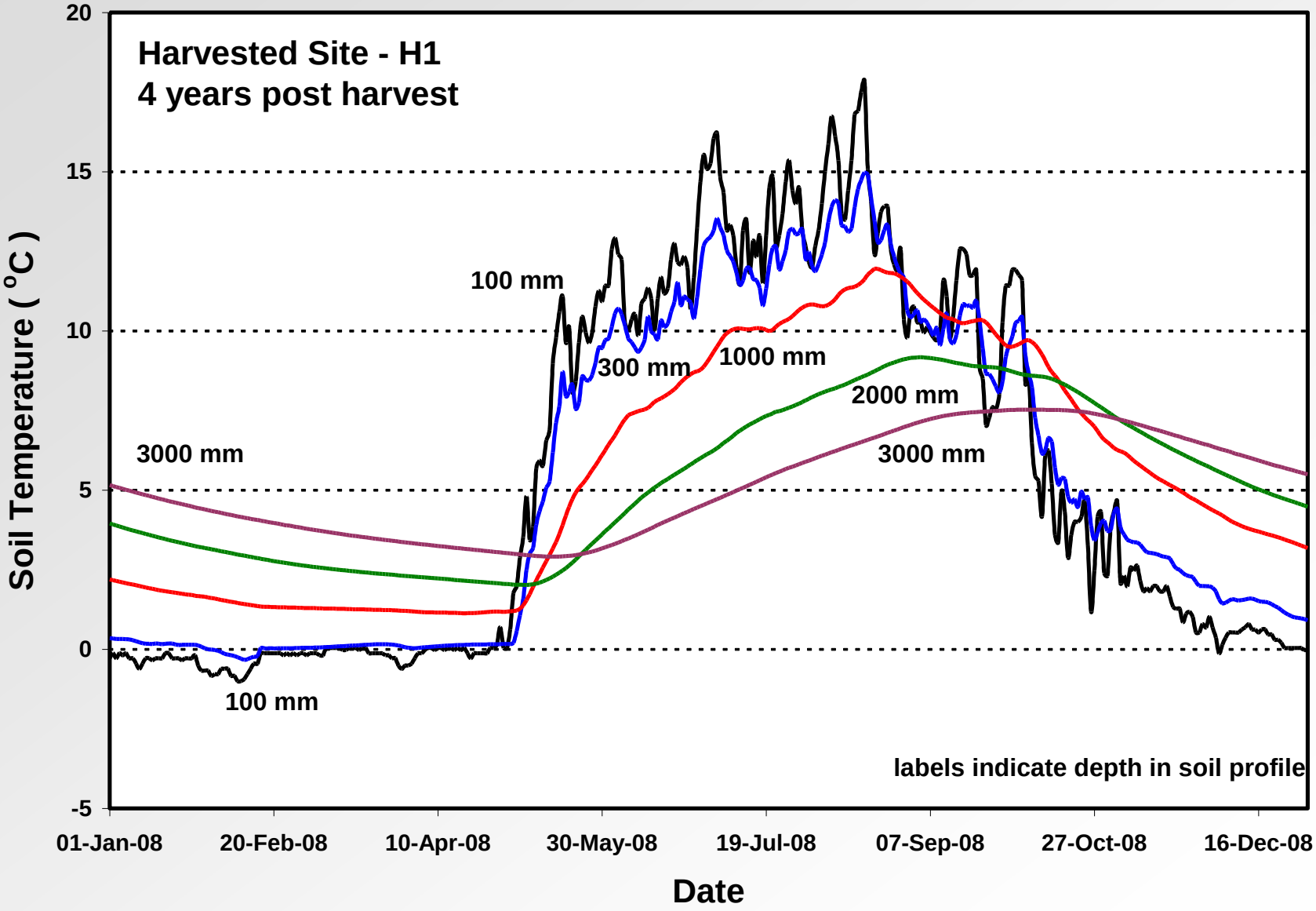
18 Automated Sites (2005/06)

- 3 Upland Harvest Sites
- 3 Upland Wildfire Sites
- 3 Upland Deciduous Sites
- 3 Upland Conifer Sites
- 3 Lowland Shallow Peat Sites
- 3 Lowland Deep Peat Site

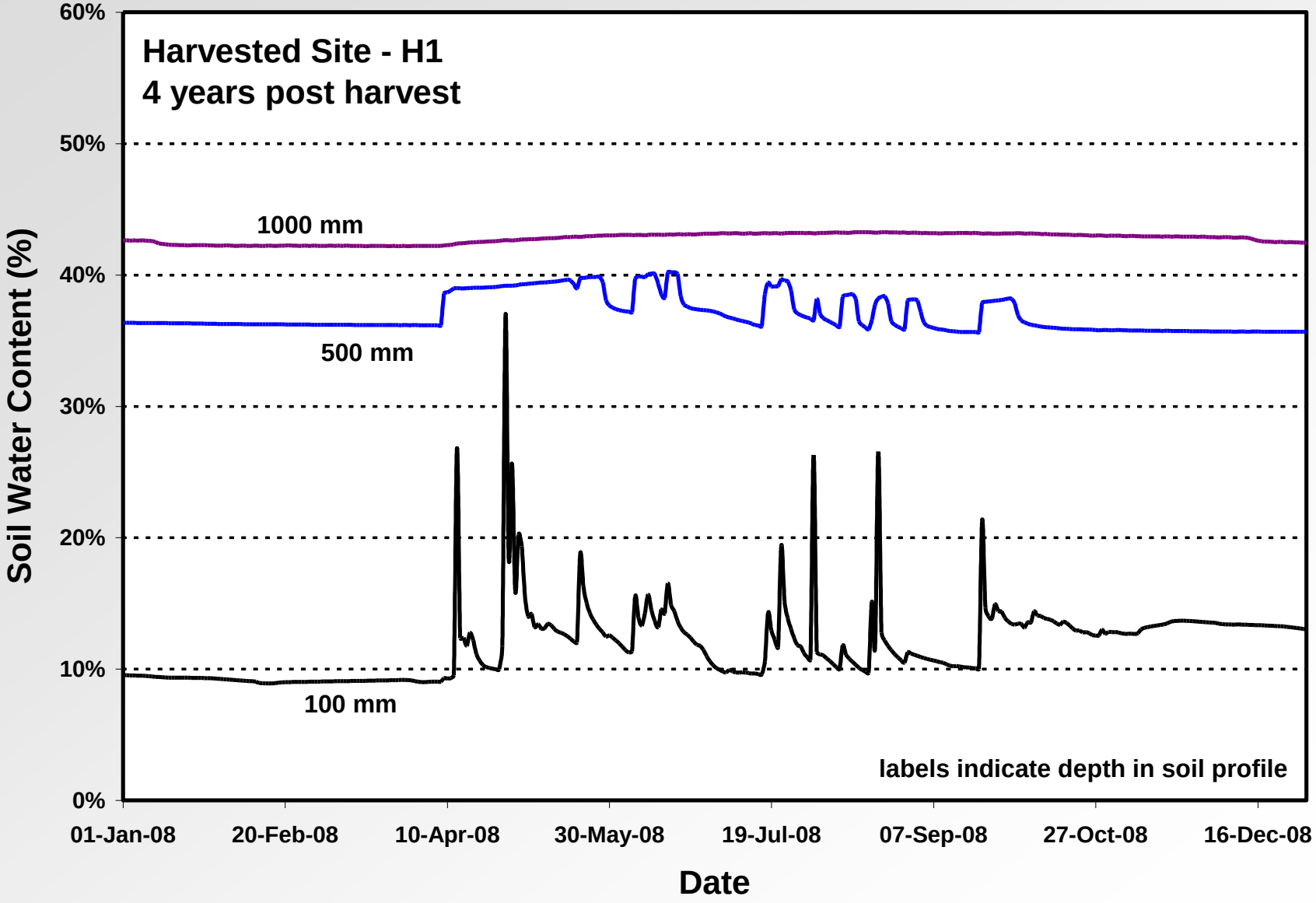
Continuous Monitoring

- Temperature @ +2000, 0, 100, 300, 500, 1000, 2000 & 3000 mm
- Water Content @ 100, 500 & 1000 mm

Soil Temperature versus Time and Depth



Soil Water Content versus Time and Depth



Soil Temperature Equation in SWAT

$$T_{soil}(z, d_n) = \lambda \cdot T_{soil}(z, d_{n-1}) + (1 - \lambda) \cdot \{df \cdot (T_{AAir} - T_{ssurf}) + T_{ssurf}\}$$

$T_{soil}(z, d_n)$	soil temperature at a specific depth z (in mm) on the current day
$T_{soil}(z, d_{n-1})$	previous day's soil temperature
λ	lag coefficient
df	depth factor
T_{AAir}	average annual air temperature based on long-term data
T_{ssurf}	soil surface temperature on the current day

All temperatures in ^{o}C

Damping Factor and Damping Depth Definition

$$df = \frac{zd}{zd + \exp\left(-0.867 - 2.078 \cdot zd\right)}$$

df	depth factor for a soil layer
zd	unitless depth ratio given by *z/dd*
z	depth at the center of the soil layer
dd	damping depth

Neitsch et al. (2005) define *dd* as the depth in the soil profile at which the soil temperature is within 5% of T_{AAir}.

Damping Depth Equations

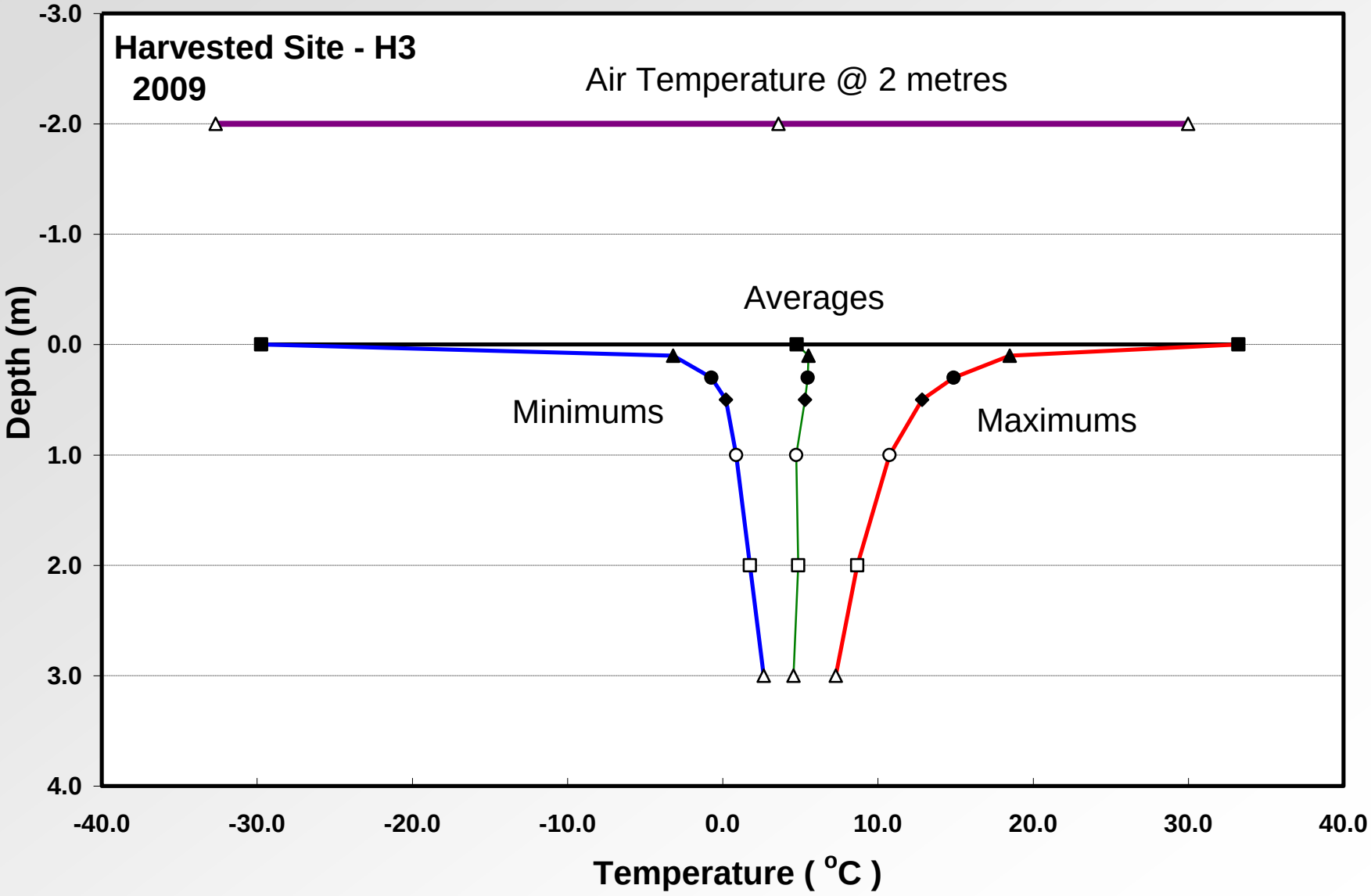
$$dd_{max} = 1000 + \frac{2500\rho_b}{\rho_b + 686\,exp(-5.63\rho_b)}$$

$$\phi = \frac{SW}{(0.356 - 0.144\rho_b)\cdot z_{tot}}$$

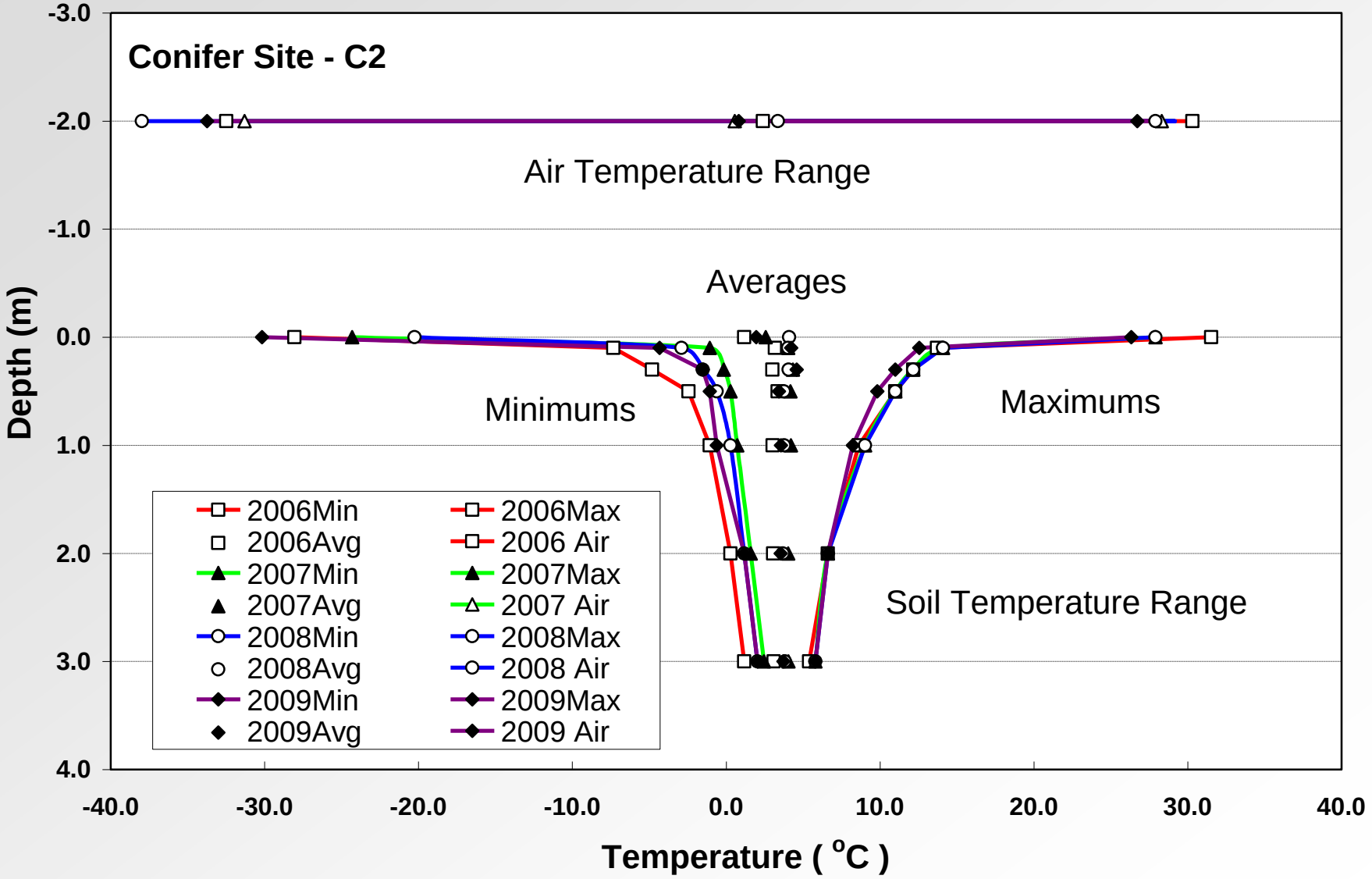
$$dd = dd_{max} \cdot exp\left[ln\left(\frac{500}{dd_{max}} \right)\left(\frac{1-\phi}{1+\phi} \right)^2 \right]$$

dd_{max}	maximum damping depth.
ρ_b	bulk density of the soil in Mg/m^3
ϕ	scaling factor based upon the water content of the soil
SW/z_{tot}	water content in the soil profile in mm/mm
SW	water in the soil profile expressed as depth in mm
z_{tot}	depth of the soil profile in mm.

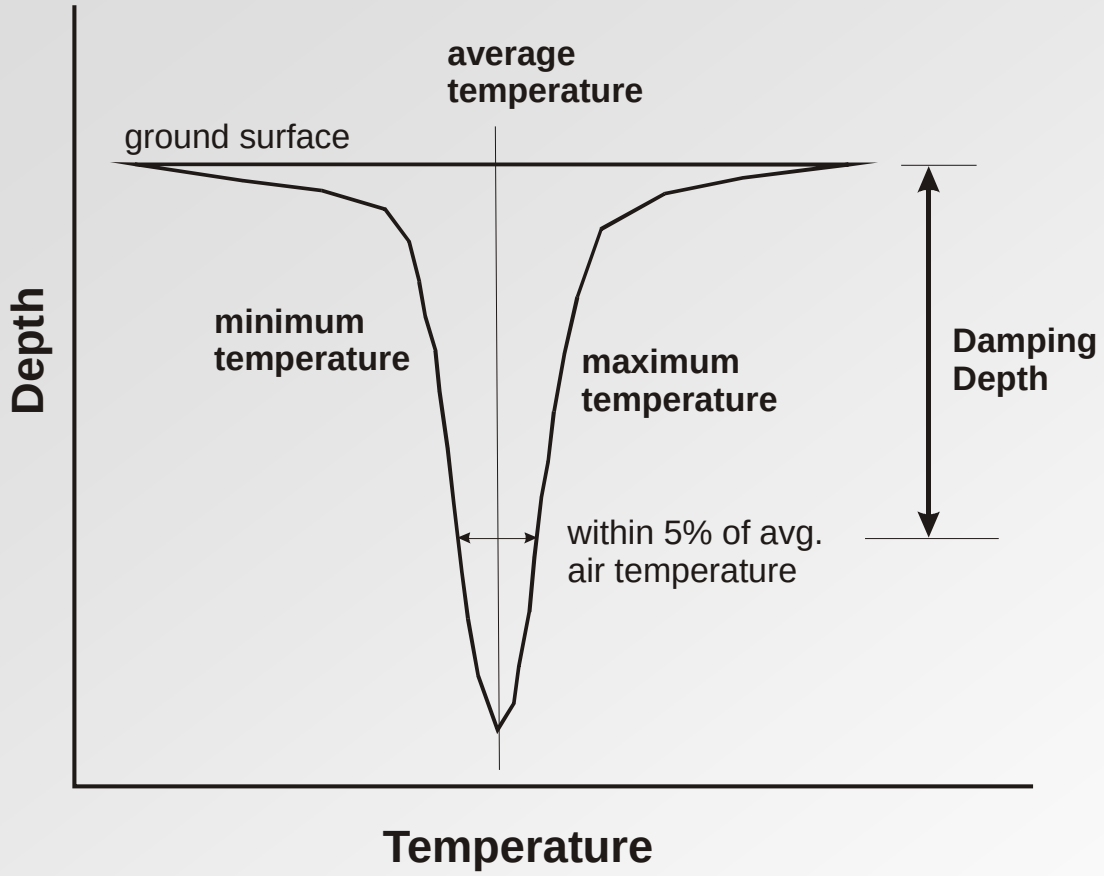
Air and Soil Temperature Range – H3, 2009



Air and Soil Temperature Range – C2

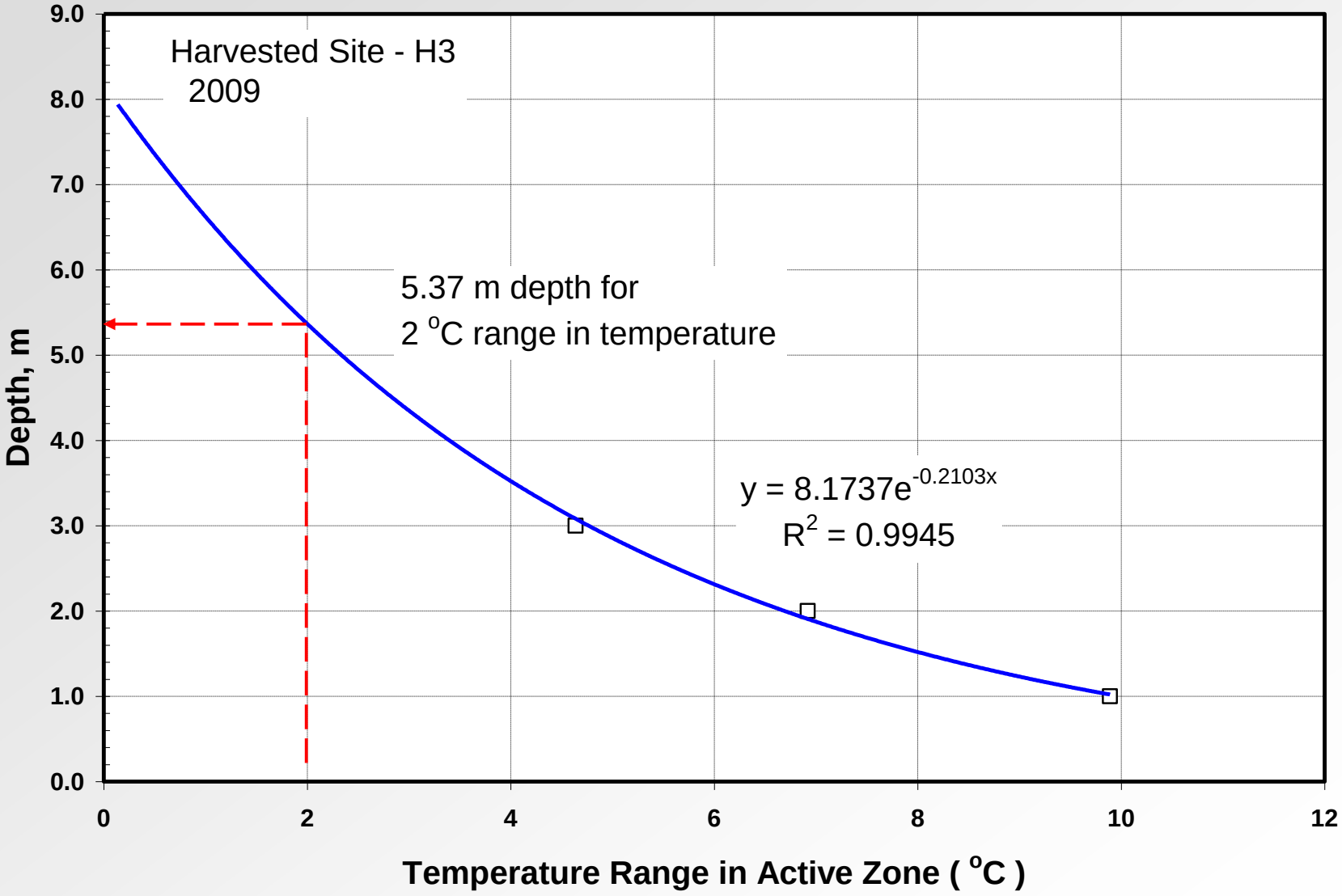


Revised Damping Depth Definition



- Avg. air temp. 20 °C
  - Within 1 °C
- Avg. air temp. 2 °C
  - Within 0.1 °C
- Propose range of 2 °C to define the damping depth
  - Nominally ±1 °C

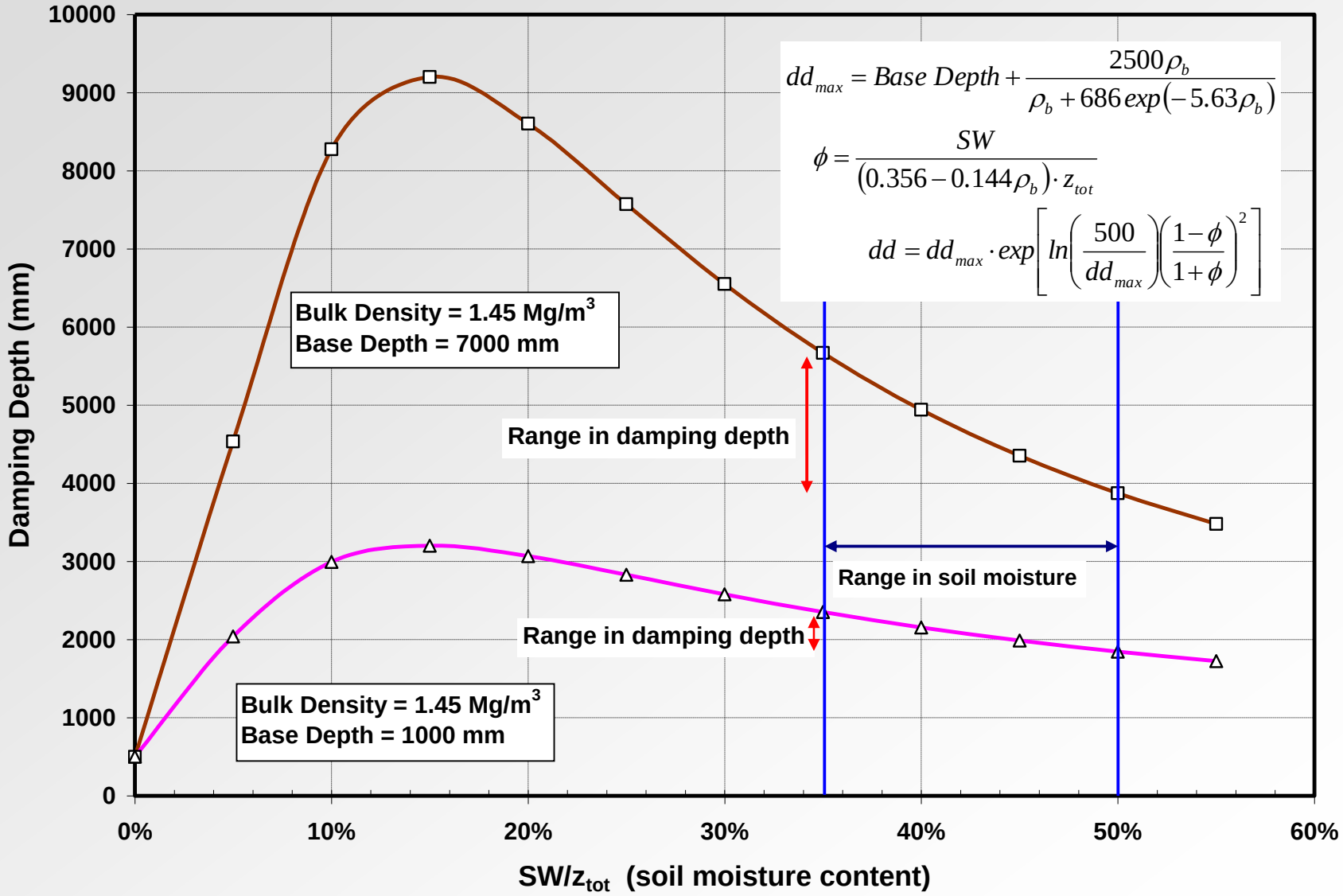
Determination of Largest Damping Depth



Largest Damping Depth and Average Soil Water Content

	Conifer Site - C2			Deciduous Site - D1			Deciduous Site - D3		
Year	avg. air temp. °C	dd m	WC @ 1m %	avg. air temp. °C	dd m	WC @ 1m %	avg. air temp. °C	dd m	WC @ 1m %
2006	2.3	4.98	39%	2.4	5.61	40%	0.5	4.13	36%
2007	0.6	4.59	41%	1.7	5.80	41%	1.8	3.93	38%
2008	3.4	4.37	41%	1.4	5.11	41%	2.9	4.17	37%
2009	0.8	4.32	39%	0.9	5.16	40%	1.7	4.34	34%
avg.	1.8	4.57	40%	1.6	5.42	41%	1.7	4.14	36%
range	2.8	0.66	2%	1.6	0.69	1%	2.4	0.41	4%

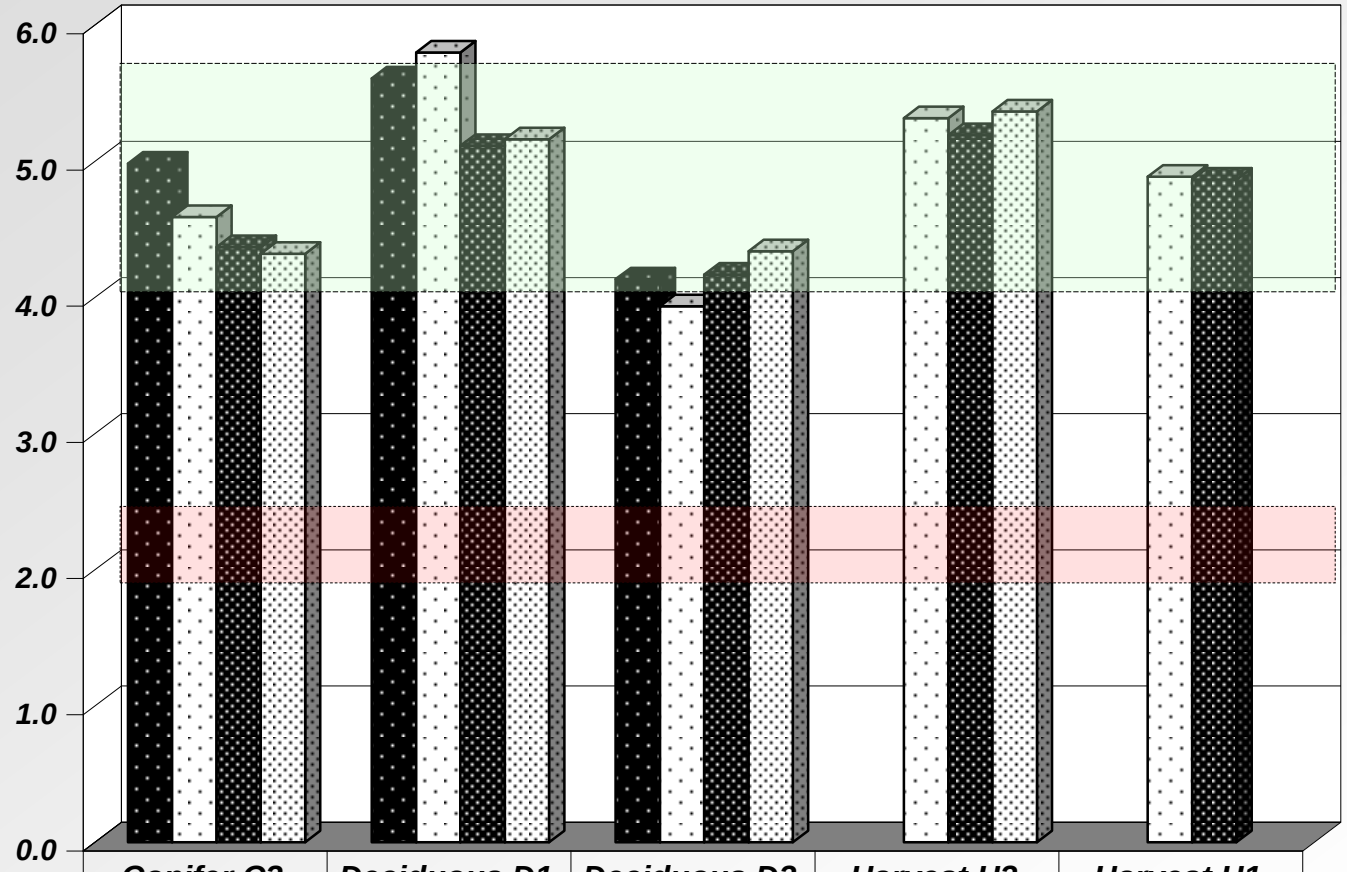
Damping Depth vs. Soil Moisture Content



Comparison of Largest Damping Depths

(3.87 to 5.67 m)
Range based upon modified Eq.5 with constant = 7000 mm

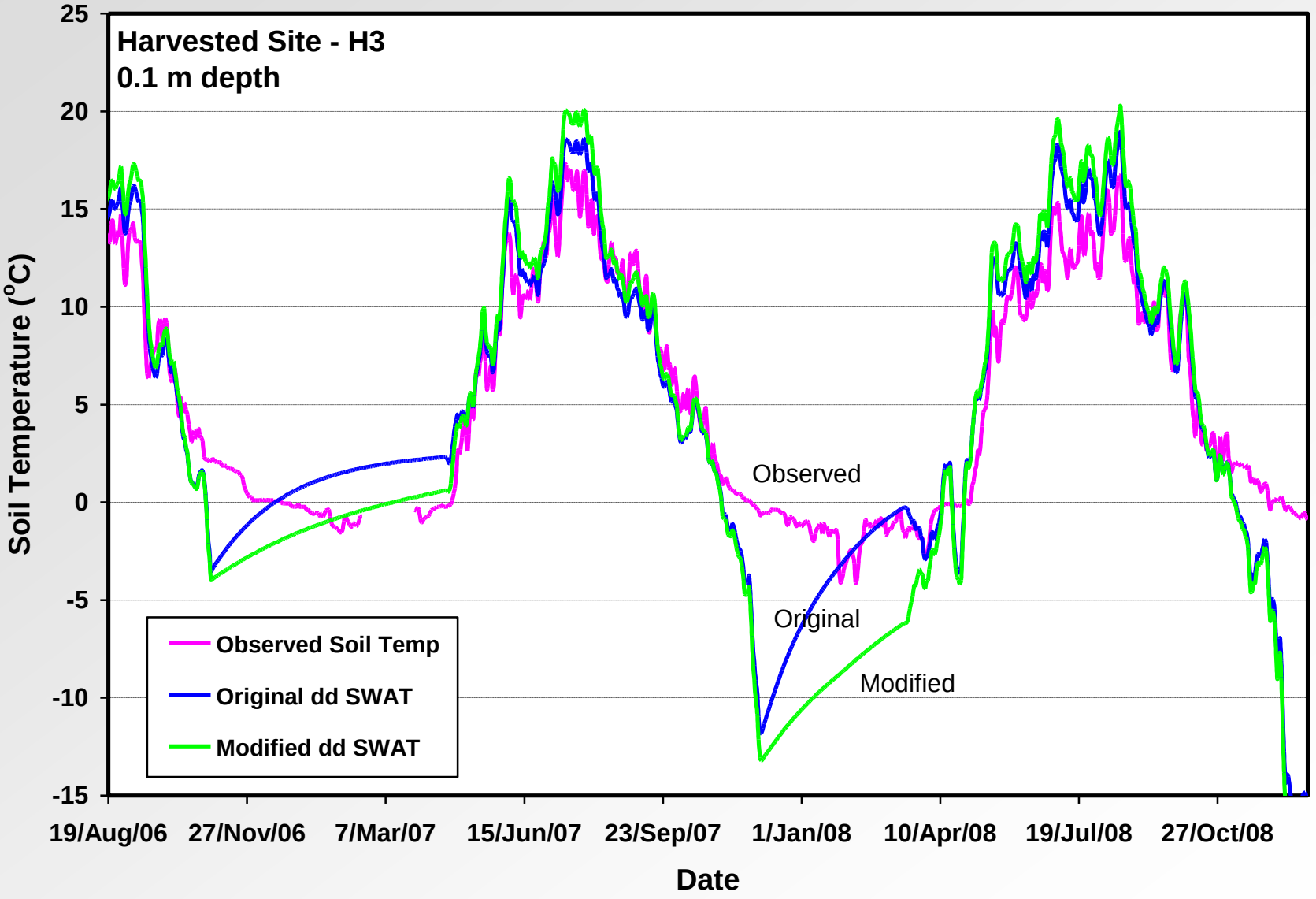
(1.85 to 2.35 m)
Range based upon original Eq. 5 with constant = 1000 mm



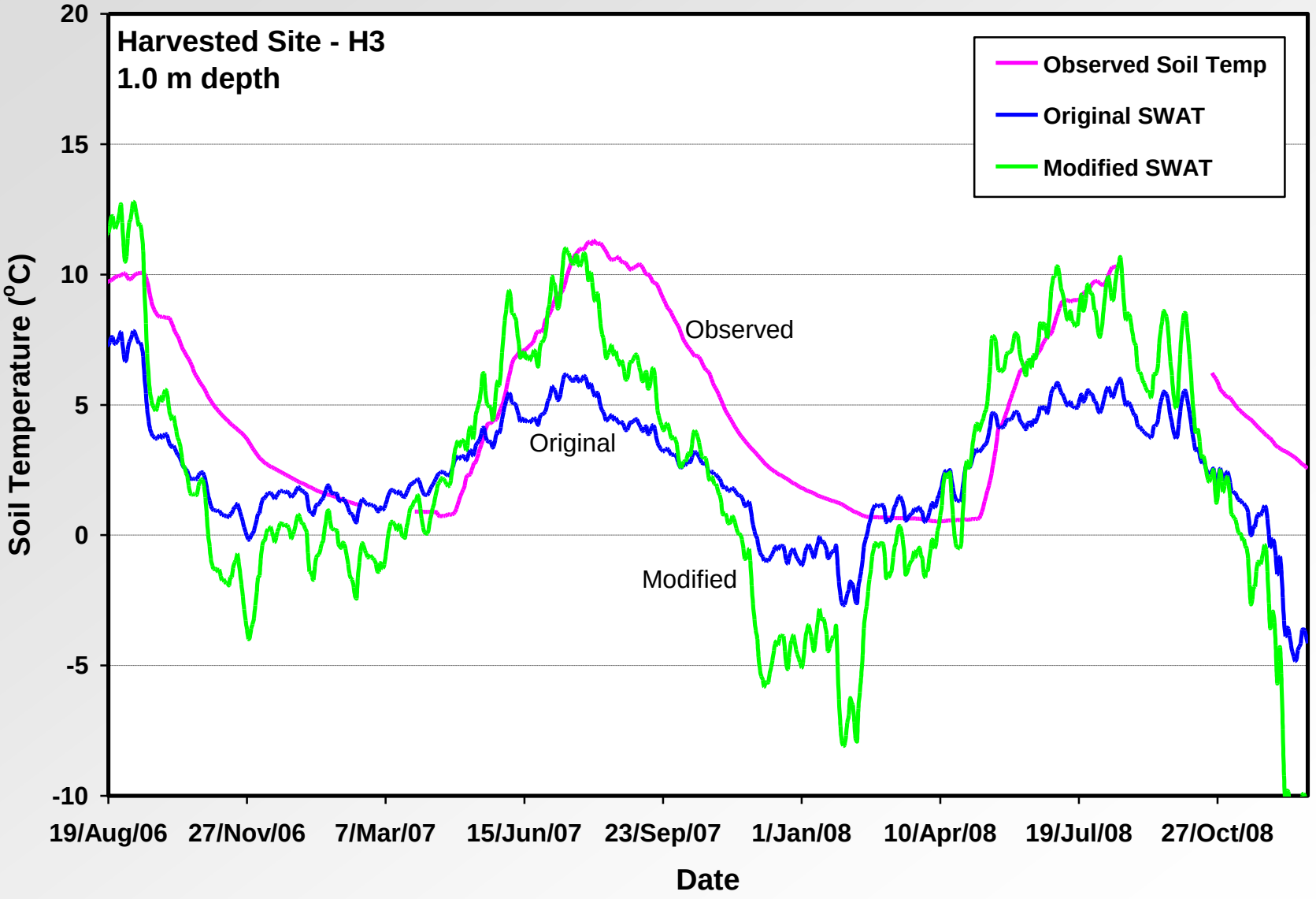
	Conifer C2	Deciduous D1	Deciduous D3	Harvest H3	Harvest H1
2006	4.98	5.61	4.13		
2007	4.59	5.80	3.93	5.32	4.89
2008	4.37	5.11	4.17	5.19	4.87
2009	4.32	5.16	4.34	5.37	

Site Type

Predicted vs. Observed Soil Temp., 0.1 m, H3



Predicted vs. Observed Soil Temp., 1.0 m, H3



Conclusions & Recommendations

- Damping depth calculation modifications are required for Boreal forest conditions
  - increasing the base depth constant improves the damping depth representation
  - a function to modify the base depth constant with latitude or annual average temperature is suggested
- The damping depth definition should be modified
  - abandon the % of T_{AAir} definition
  - adopt an absolute definition (eg. 2 ^{o}C range in temp.)
- Improved damping depth representation provides
  - significant effect upon soil temp. calc deep in soil profife
  - little effect upon near surface temperatures

Forest Watershed & Riparian Disturbance Project

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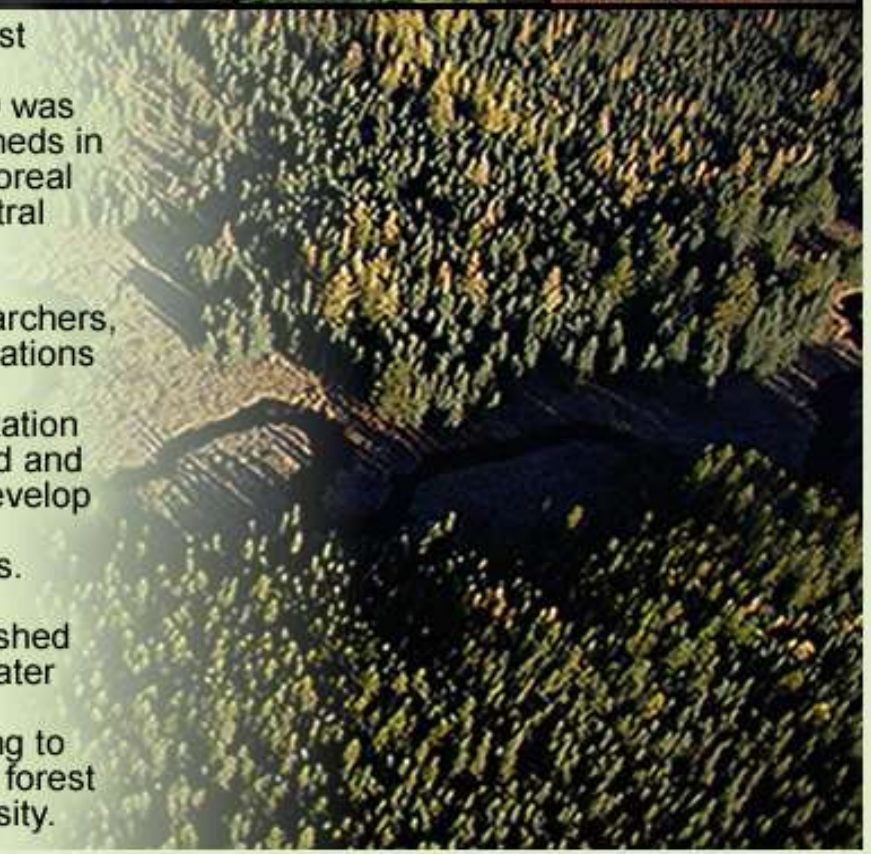
Linking research & industry to improve forest management planning in Canada

Link to the data request site here!

Welcome to the official website of the Forest Watershed and Riparian Disturbance (FORWARD) research project. FORWARD was initiated in 2001, and has research watersheds in the Swan Hills on the western Canadian Boreal Plain, and in the Legacy Forest on the central Canadian Boreal Shield.

FORWARD is a partnership between researchers, students, forest-related companies, First Nations communities, and Provincial and Federal Governments. We collect soil, water, vegetation and amphibian data from reference, burned and experimentally harvested watersheds to develop models that can be linked directly to the management plans of our Industry Partners.

The models we develop predict how watershed disturbance influences the movement of water and nutrients from forests to streams. Experimental work tests hypotheses relating to watershed processes that influence boreal forest soils, hydrology, water quality and biodiversity.



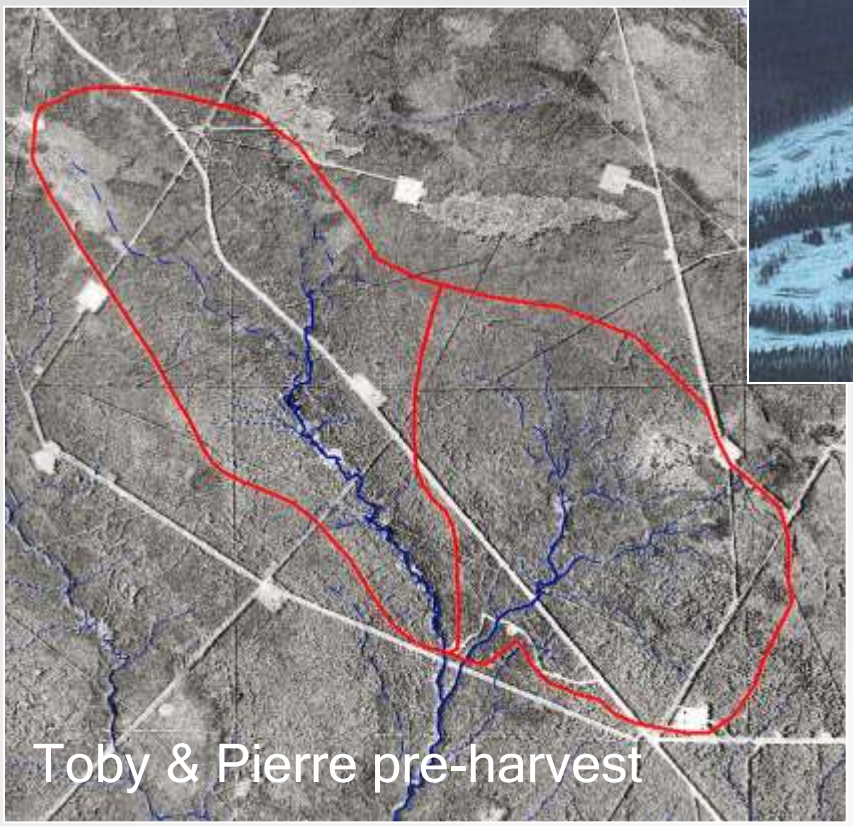
Feedback to: janicemarion@yahoo.com

Last Updated 30 May 2011

http://forward.lakeheadu.ca

- Additional slides not used in presentation!

Photo credit: Tom Plaulfe

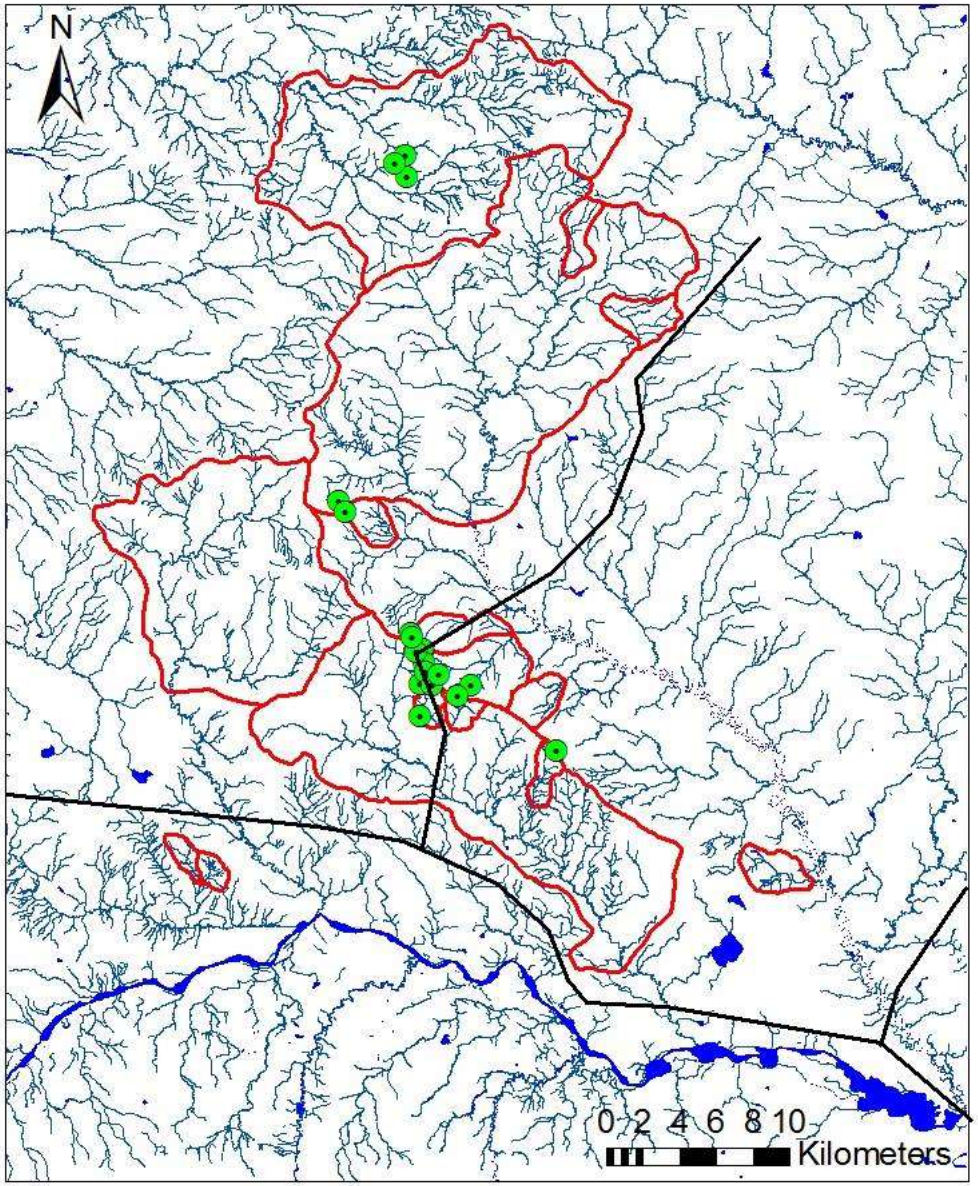


Toby & Pierre pre-harvest

Watershed Harvest – Winter of 2003/2004

Examples of vegetation 3rd summer post harvest

- Upper elevations
- 7 watersheds
- 198 sensors (702 tiny wires) = steady maintenance



Harvested, Conifer and Deciduous Sites

Site ID	Landcover	Species Cover (approx %)*	Canopy Cover (%)	Elevation (m)
H1	Harvested	n/a	0	1016
H2	Harvested	n/a	0	991
H3	Harvested	n/a	0	1043
C1	Conifer	PL(90) AW(10)	92	1028
C2	Conifer	PL(90) AW(10)	97	1005
C3	Conifer	PL(90) AW(10)	89	1054
D1	Deciduous	AW(70) SB(20) PL(10)	84	1053
D2	Deciduous	AW(60) SB(20) PL(20)	96	1026
D3	Deciduous	AW(90) PL(10)	95	1013

*** PL: lodgepole pine, AW: trembling aspen, SB: black spruce.**

Largest Damping Depth and Average Soil Water Content

	Harvest Site - H1			Harvest Site - H3		
Year	avg. air temp. °C	dd m	WC @ 1m %	avg. air temp. °C	dd m	WC @ 1m %
2006	-	-	-	-	-	-
2007	2.8	4.89	42%	3.8	5.32	55%
2008	3.2	4.87	43%	2.8	5.19	45%
2009	-	-	-	3.6	5.37	47%
avg.	3.0	4.88	43%	3.4	5.29	49%
range	0.4	0.02	1%	1.0	0.17	10%