Importance of moisture transport, snow cover and soil freezing to ground temperature predictions

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Background

- Ground temperatures of interest for:
  - Building foundation – ground heat transfer
  - Ground-source heat pump systems
  - District heating and cooling systems
- Available models to provide *GT=f(date, depth)*
  - Kusuda and Achenbach (1965)
- Other models

Limitations of Harmonic Models

- Shortage of data
- Applicability to colder climates?
- Possible improvements:
  - Update the data
  - Revise the equation form or
  - Develop new procedure

Possible Approach

- Numerical simulation of ground using
  - Typical Meteorological Year type files or equivalent
  - ASHRAE will release 3012 IWEC-2 files
- How detailed does ground simulation need to be?

This investigation

- Looks at winter conditions and the need for modeling:
  - Moisture transport
  - Soil freezing/thawing
  - Snow cover
- Our approach:
  - Compare model permutations to experimental results

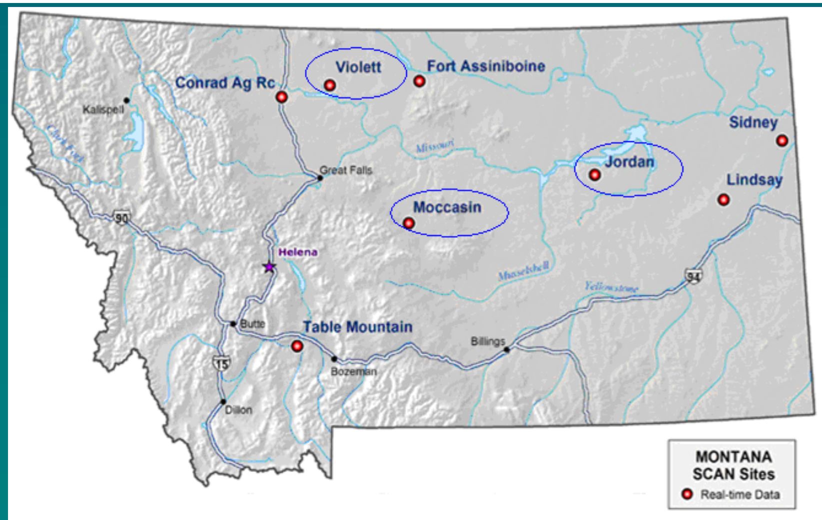
Experimental measurement

- Data source

US Department of Agriculture's Soil Climate Analysis Network

Precipitation during test period

Location (Test period dates)	Rainfall(mm)	Snowfall in water equivalent(mm)	Total(mm)
Violett (2006.11-2007.4)	65	80	145
Jordan (2007.11-2008.4)	28	50	78
Moccasin (2006.11-2007.4)	62	78	140



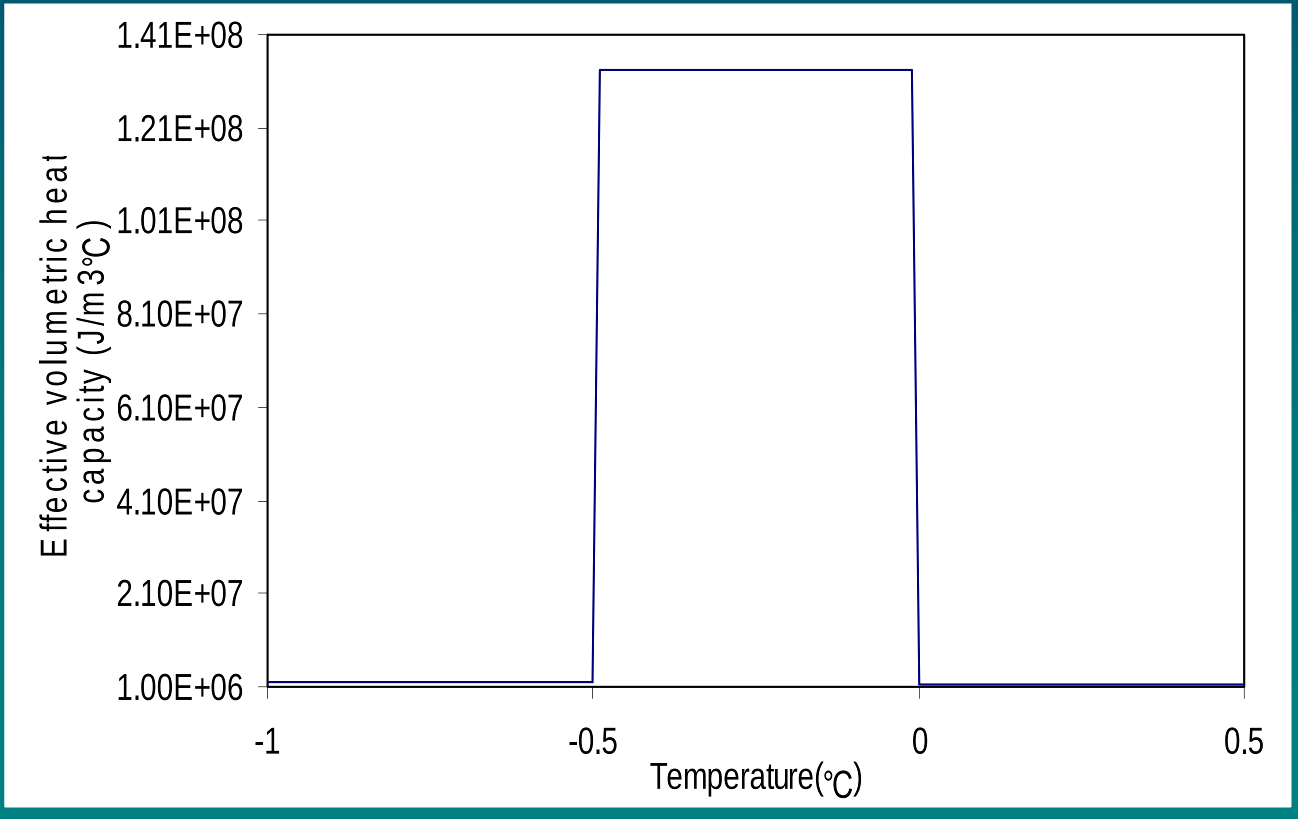
Experimental measurement sites
(http://www.wcc.nrcs.usda.gov/scan/Montana/montana.html

Modeling approach

- A 2-d explicit finite difference model was adapted for the work.
- 4x569 square cells – 9mm
- Domain is 5 m deep
  - Boundary conditions:
  - Side: adiabatic
  - Top: full heat balance except ET
- Bottom: constant temperature

Snow and soil freezing / thawing

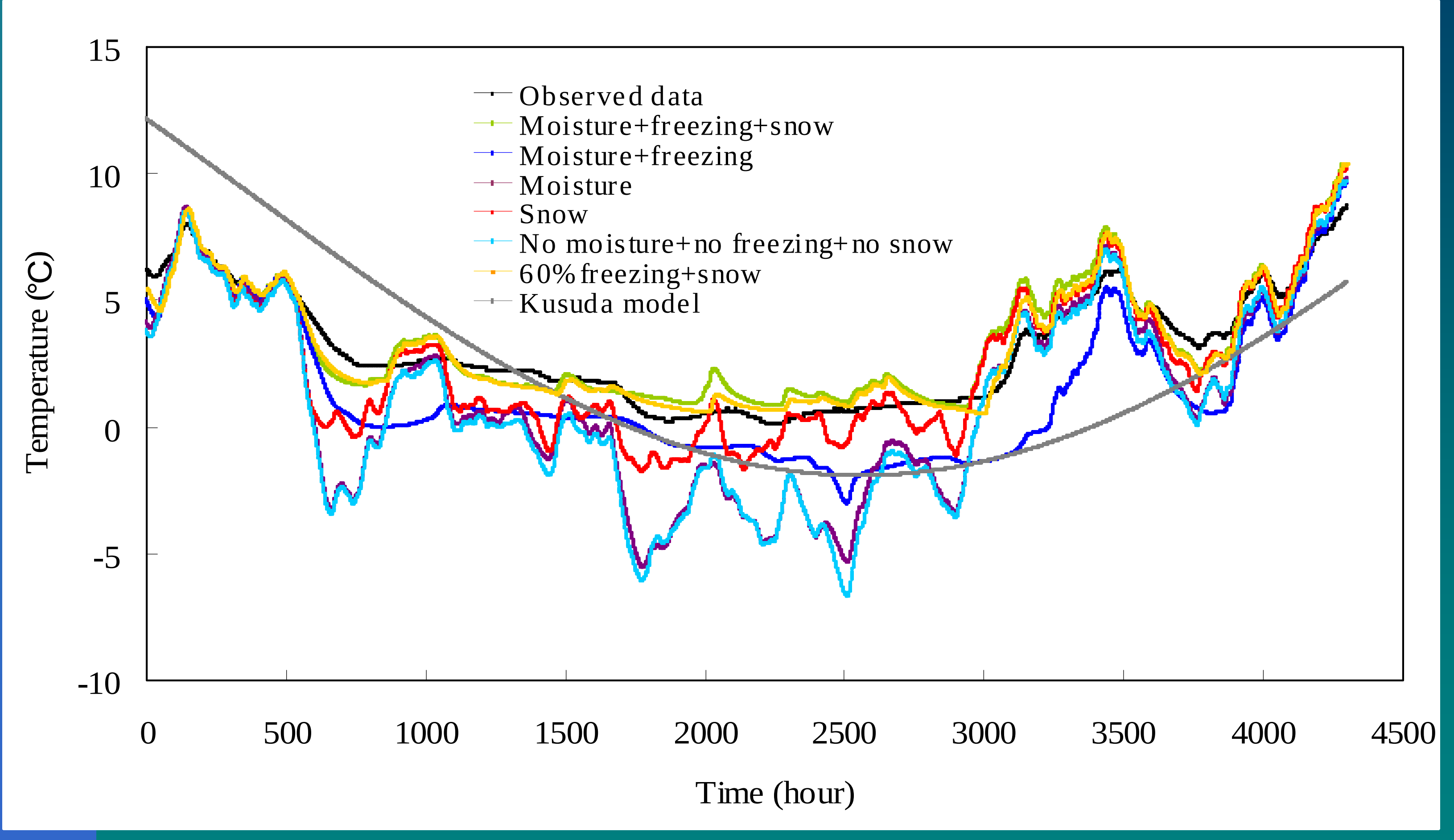
- Detailed snow accumulation/melting
- Effective capacity model



Modeling – Moisture Transport

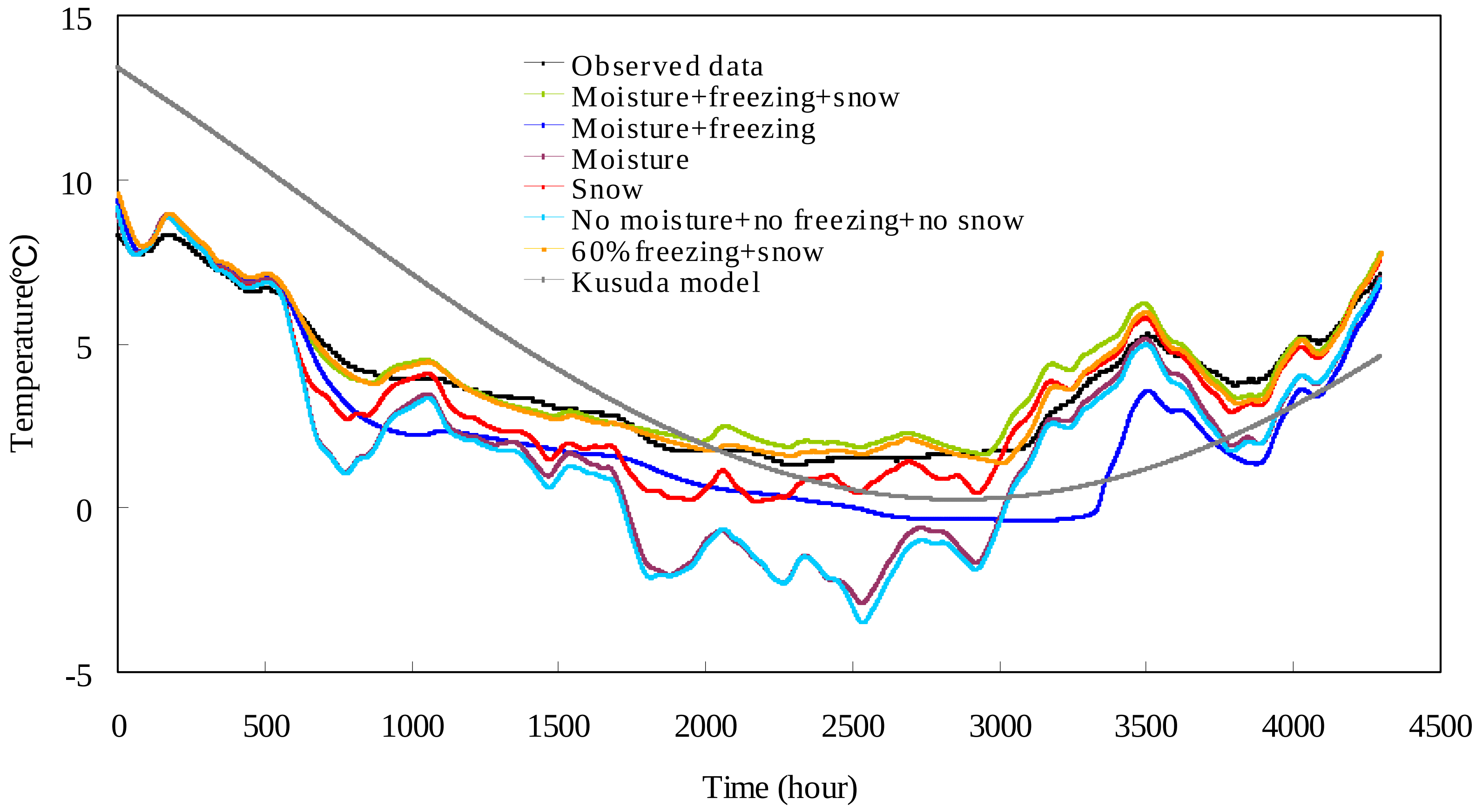
- Moisture transport due to moisture and temperature gradients: Philip and DeVries (1957)
- Impedance of ice accounted for
- Above and freezing validated against laboratory experiment.
- Precipitation, evaporation and condensation at the surface – limited by "maximum absorption capacity"

Results and discussion



Moccasin,0.5m

Results and discussion



Moccasin,1.0m

RMSE

Model features				CPU time, min	0.5m, ℃			1.0m, ℃		
Moisture	Freezing	Snow	Saturation		Violett	Jordan	Moccasin	Violett	Jordan	Moccasin
×	×	×	0%	12	5.1	2.7	2.8	4.4	3.0	2.3
√	×	×	–	139	4.7	2.3	2.6	4.2	2.4	2.1
×	×	√	0%	16	3.1	1.8	1.3	2.7	1.9	0.9
√	√	×	–	146	4.4	1.5	1.9	3.7	2.0	1.7
√	√	√	–	167	1.9	1.4	0.8	1.5	0.7	0.5
×	√	×	0%	18	5.1	2.7	2.8	4.4	3.0	2.3
×	√	×	20%		4.3	1.6	2.2	3.8	2.0	1.9
×	√	×	40%		4.2	1.5	2.2	3.7	1.8	1.9
×	√	×	60%		4.3	1.7	1.8	3.6	1.7	1.5
×	√	×	80%		3.9	1.8	1.8	3.3	1.6	1.5
×	√	×	100%		3.9	2.3	1.7	3.3	1.3	1.4
×	√	√	0%	19	3.1	1.8	1.3	2.7	1.9	0.9
×	√	√	20%		2.5	1.2	0.9	2.3	1.0	0.5
×	√	√	40%		2.3	1.6	0.8	2.1	1.1	0.5
×	√	√	60%		2.1	2.0	0.6	2.0	1.2	0.4
×	√	√	80%		2.0	2.1	0.8	1.9	1.3	0.5
×	√	√	100%		2.0	2.6	0.8	1.9	1.5	0.6
Kusuda and Achenbach Model				–	4.6	2.3	2.9	3.2	1.9	2.4

Conclusions

- Modeling moisture transport gives slight increase in accuracy & large increase in computational time
- Approach seems to be feasible, but:
  - Using TMY-type weather files still unproven
  - TMY-type weather files often do not contain precipitation data
- Equivalent moisture content of 40%-60% saturation should be tested in wider range of climates.

Questions & Comments