Coupling Transport and Transformation Model with Land Surface Scheme SABAE-HW: Application to the Canadian Prairies

Allan D. Woodbury, Alireza Hejazi
Department of Civil Engineering
University of Manitoba

DRI Workshop
Winnipeg, MB
May 2010

Acknowledgements

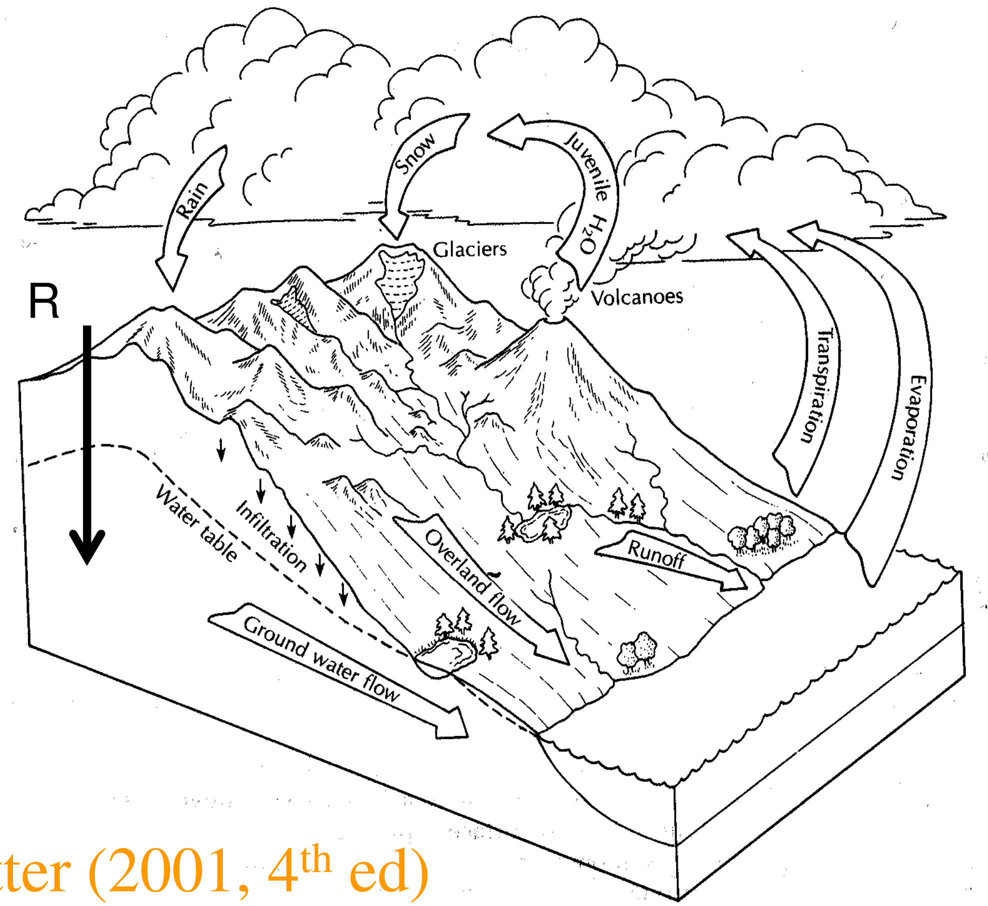
- Ph.D. thesis work by Alireza Hejazi
- Garth Van der Kamp (Sask Research)
- Wole Akinremi (U. Manitoba)
- Yefang Jiang (PEI Water Stewardship)
- Youseff Loukili (MB Water Stewardship)
- Lei Wen, Charles Lin (McGill)
- Dr. Ken Snelgrove (Memorial)

Motivation and Specific Objectives

- Motivations:
  - Climate and land use changes are (or will) occur in over the prairies
  - What are the local and regional impacts of these changes on water quality and the environment?
  - Accurate portrayal of land surface essential
  - Nutrient transport under winter conditions not well understood

Background

- How do we deal with linkage of aquifers to the atmosphere now?

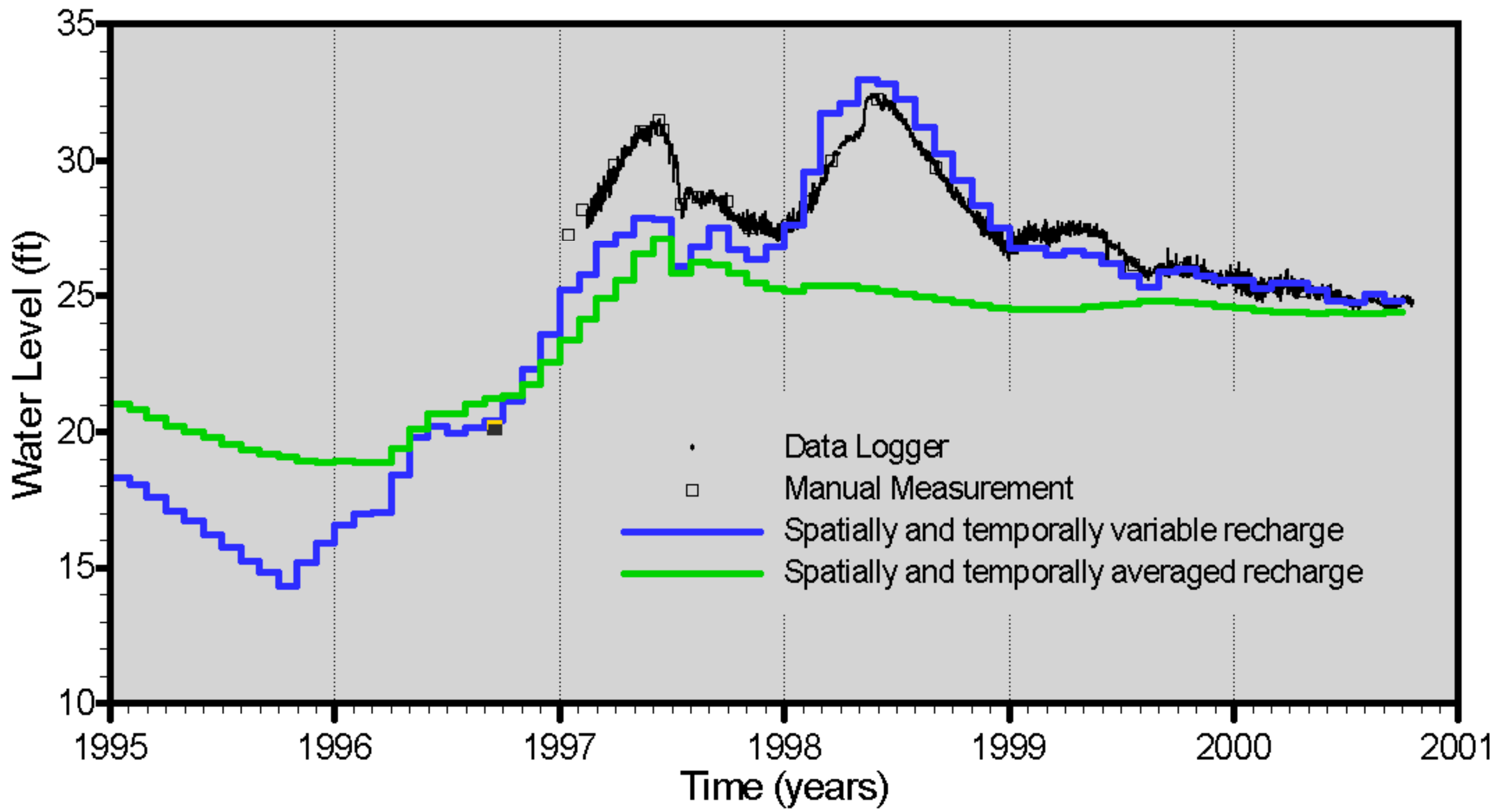


Source: Fetter (2001, 4th ed)

Laural Creek Results

Courtesy of M.I. Jyrkama

- Impact of **recharge** boundary condition on **groundwater** flow



Simulated vs. observed water levels at a monitoring well

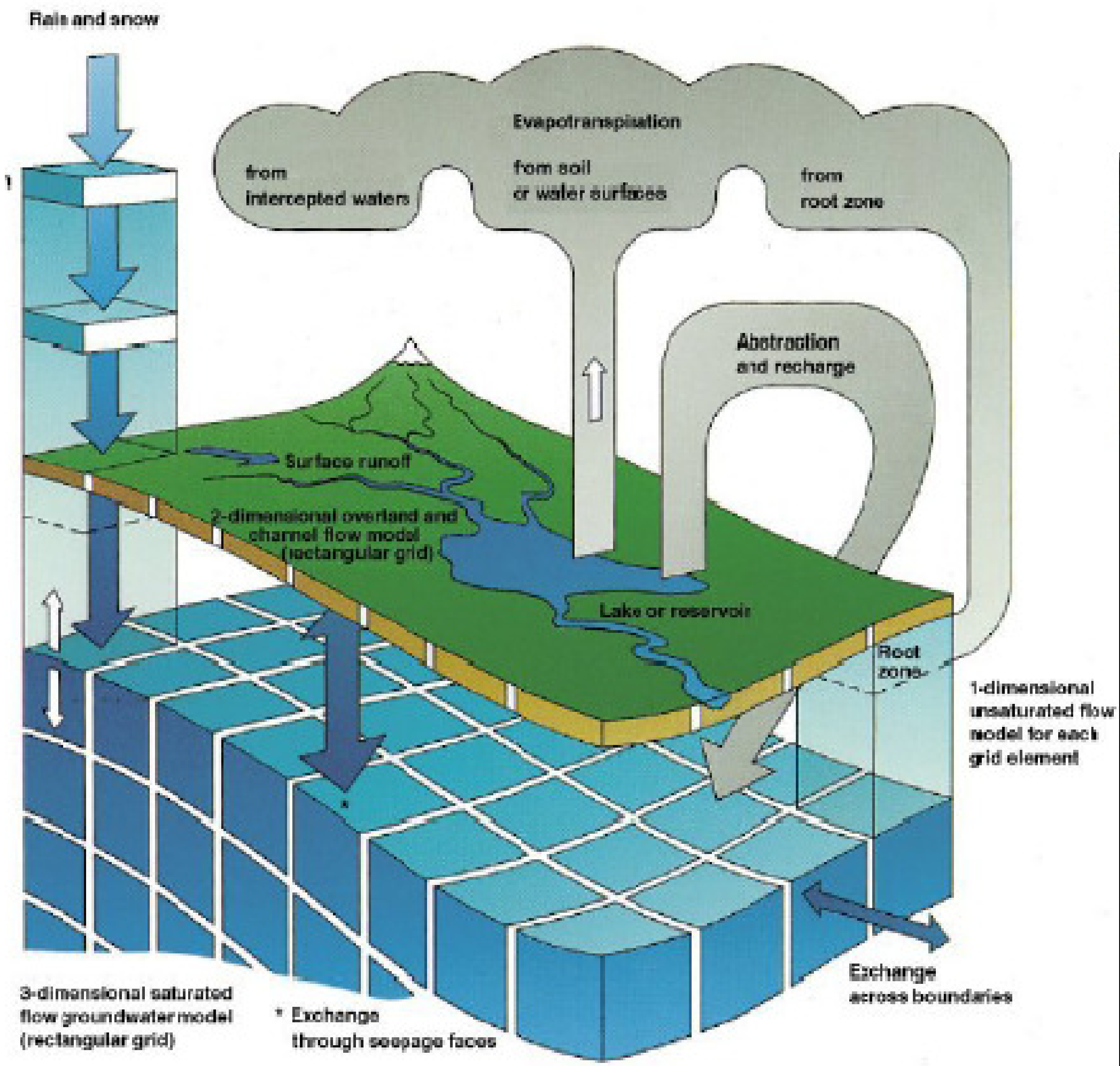
HELP3

- Hydrologic evaluation of landfills
- Inputs are climate data based on broad characterizations
- Output is the drainage out of the bottom layers, temporally variable
- A number of 1-D columns then gives us spatial and temporal variability

Problems

- HELP3 developed for landfill cover design
- Over predicts drainage
- Does not adequately address physics of coupled climate boundaries
- Land surface schemes (connected to atmospheric models) not adapted for hydrology and groundwater aquifers
- Does not solve for mass transport

Coupling Strategy



GCM

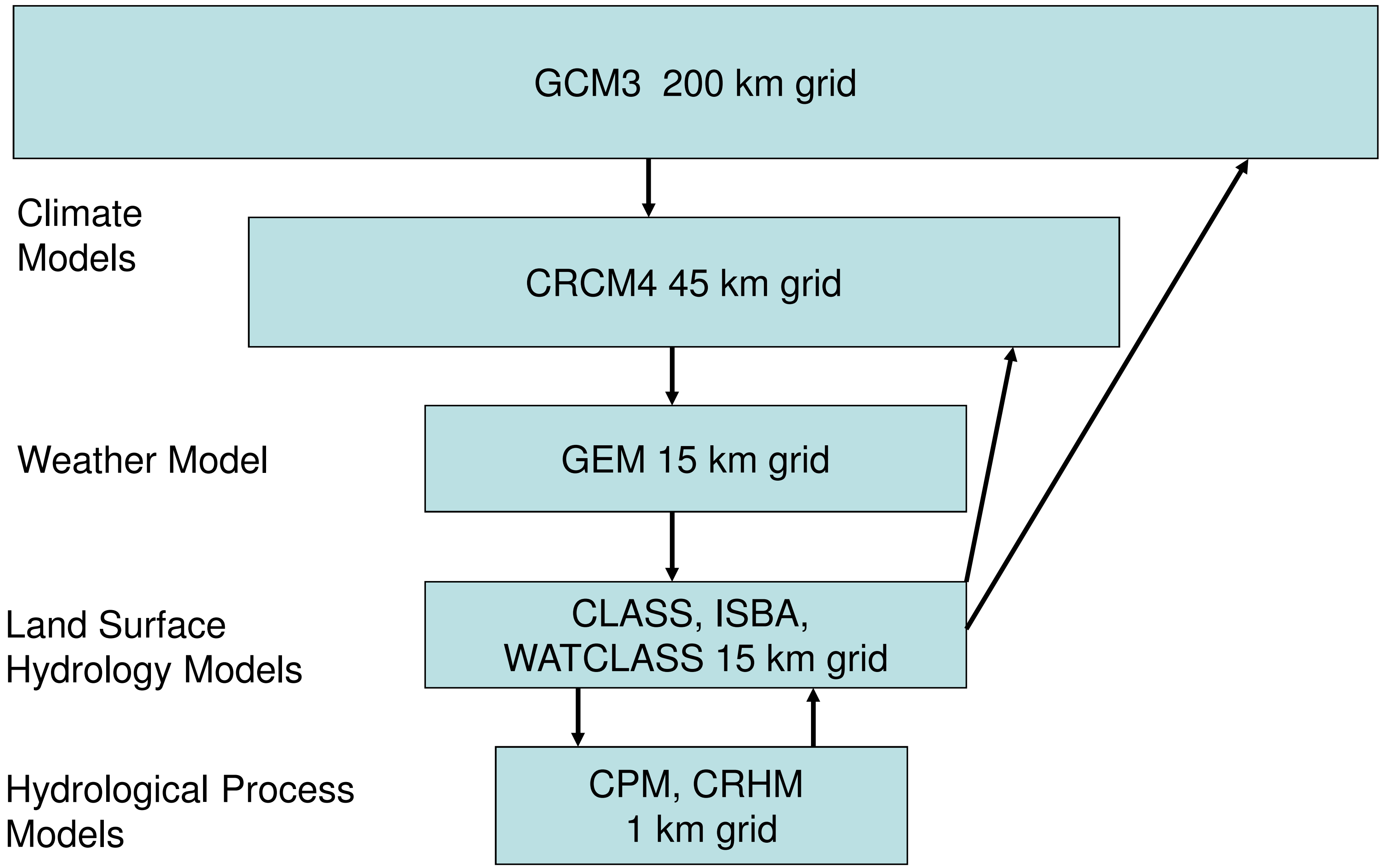
(Atmosphere)

CLASS

(Land Surface)

Groundwater

Atmospheric Models



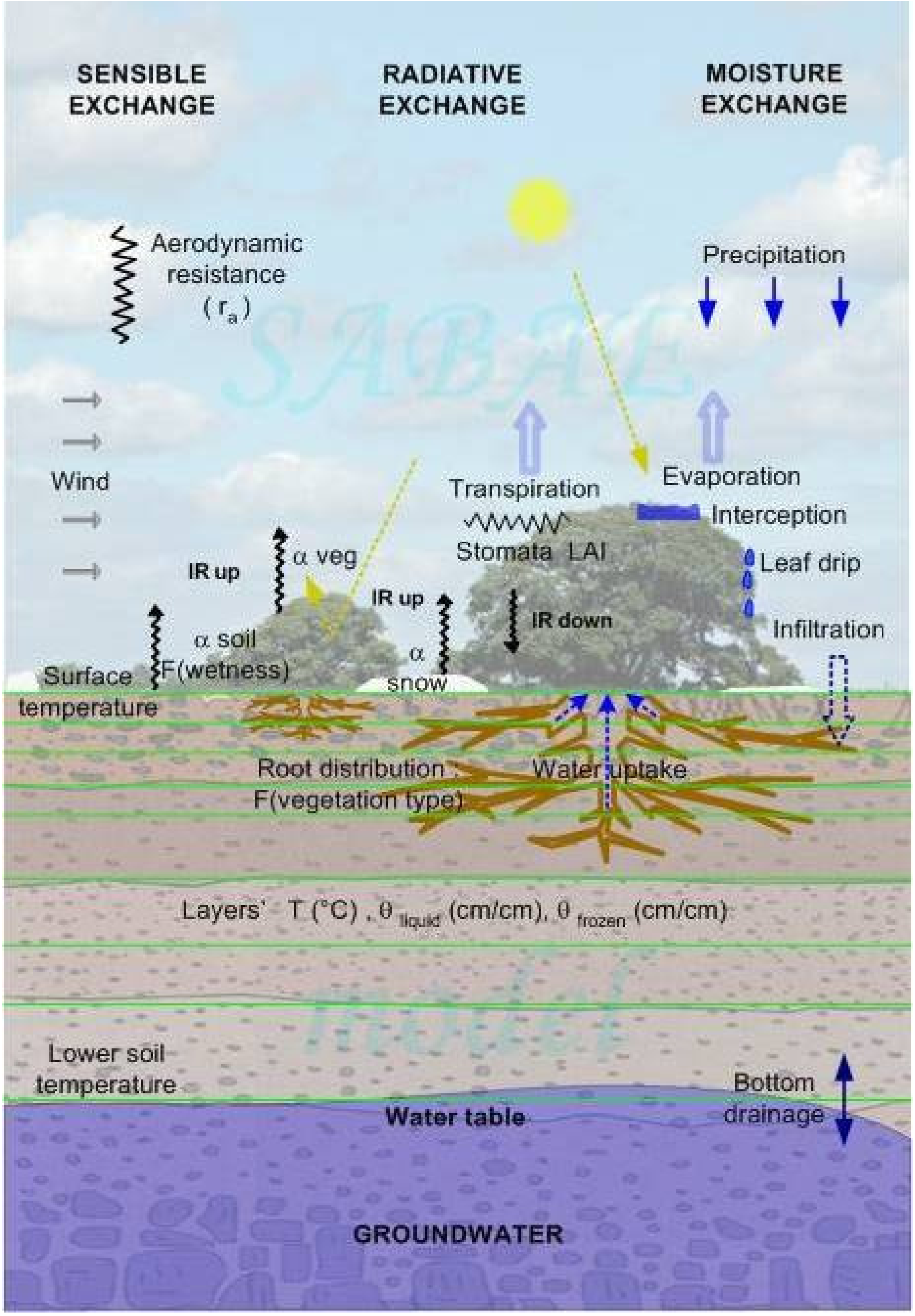
Direction

- Improve the Canadian land surface scheme (CLASS)
  - More flexibility with BC's
  - More accurate and can adequately simulate soil moisture, temperature and snow pack
- Improve estimates of spatial recharge to the soil horizons
- Add nutrient and/or carbon cycle

SABAE-HW

Soil Atmosphere Boundary, Accurate Evaluations of Heat and Water

1. Free choice of soil column depth and layers in SABAE-HW
2. More accuracy in the water mass balance terms
3. Efficient coupling with groundwater models through water table b.c.
4. Complete update of CLASS v 2.6 to Fortran 90/95
5. Extensive validation and inter-comparisons to other models (HELP, SHAW, HYDRUS)



Meteorological inputs required by CLASS and SABAE-HW :

1. Incoming long wave and short wave solar radiation
2. Precipitation
3. Wind speed
4. Air temperature
5. Atmospheric pressure
6. Specific humidity , or relative humidity

Soil characteristics (Clapp and Hornberger model)

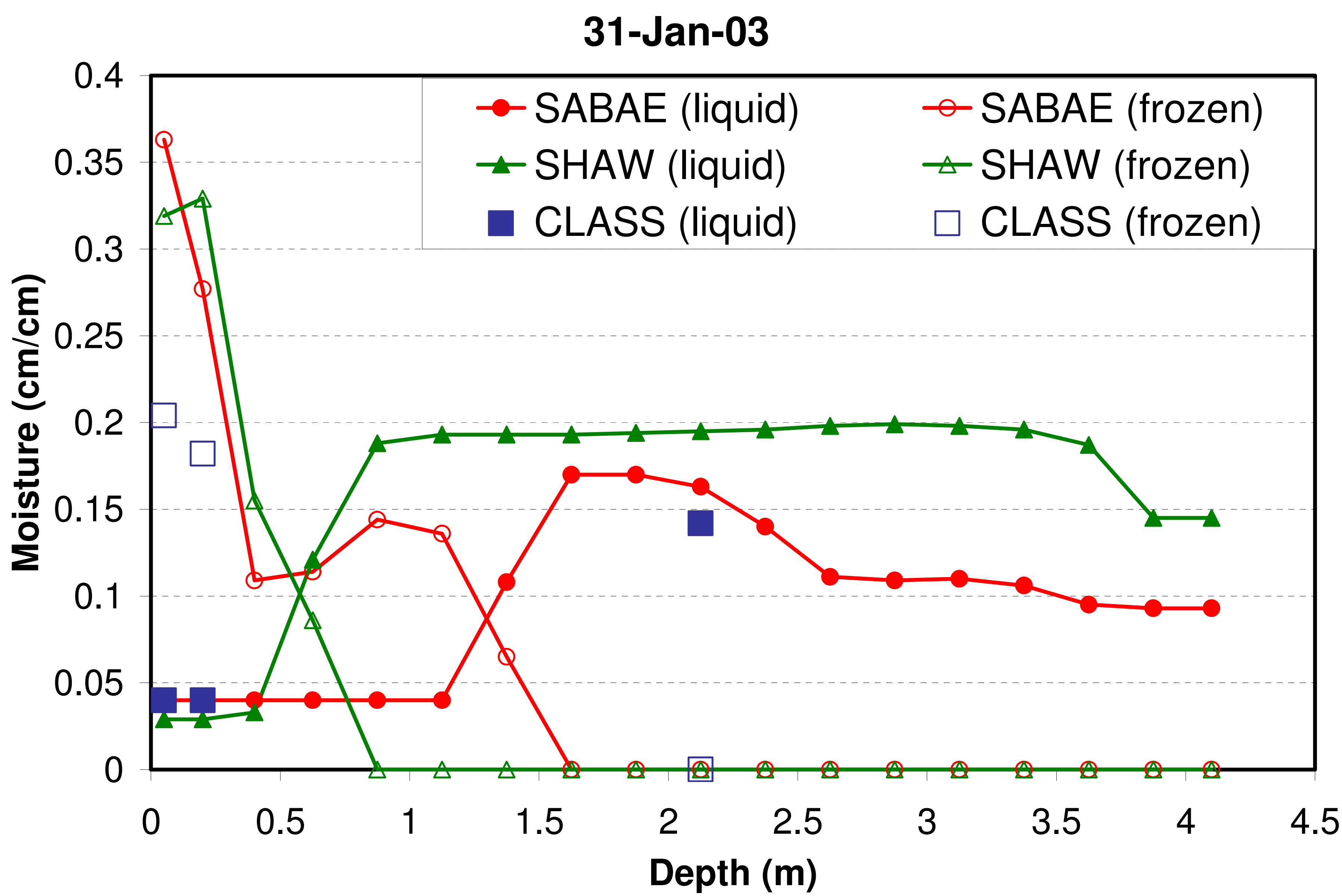
Vegetation parameters

Output :

1. Surface, canopy, snow and soil layer temperatures
2. Liquid and frozen water contents
3. Surface heat flux
4. Net absorbed short and long wave radiations
5. Sensible and latent heat fluxes
6. Water evaporation, pond and bottom drainage
7. Snow accumulation and snow melt

Comparisons

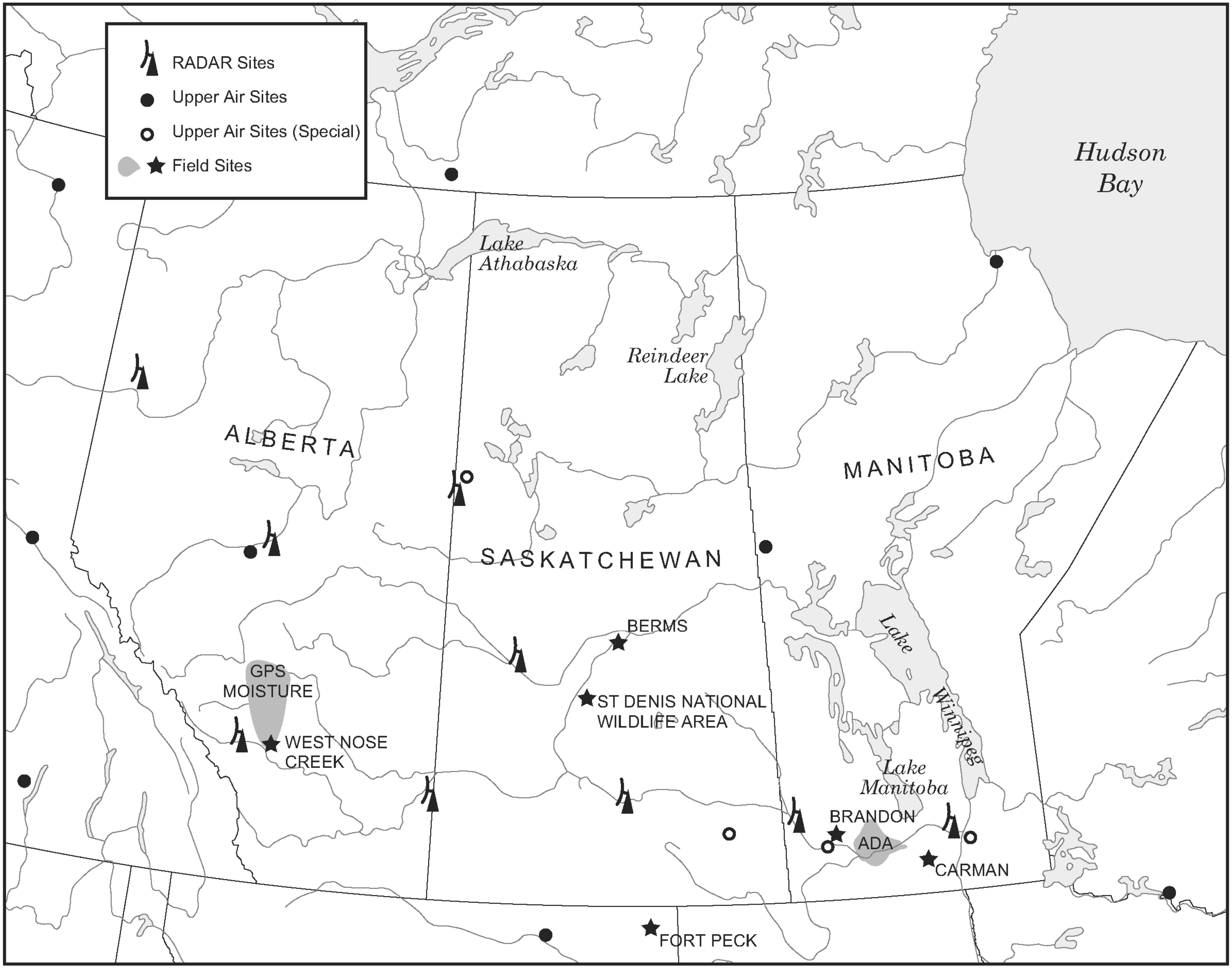
- Loukili, Y. , Snelgrove, K.R., and A.D. Woodbury, SABAE-HW – An enhancement of the water balance prediction in the Canadian Land Surface Scheme, *Vadose Zone J.*, 2008.
- Loukili, Y. and D. D. Woodbury, ABAE-HW3D: a Meteor-Hydrological Model Coupling the Land Surface to Groundwater Flow, *Eos Trans. AGU, 88*(52), Fall Meet. Suppl., 2007
- Loukili, Y., Woodbury, A.D. and K.R. Snelgrove, AccuCLASS - an Enhancement of the Canadian Land Surface Scheme for Climate Assessment Over the Prairies, *Eos Trans. AGU, 87*(52), Fall Meet. Suppl., 2006
- Field Testing Assiniboine Delta Aquifer (ADA)



31-Jan-03
SABAE (liquid)
SABAE (frozen)
SHAW (liquid)
SHAW (frozen)
CLASS (liquid)
CLASS (frozen)
Moisture (cm/cm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

MODEL Verification

- Field site with recorded data in Saskatchewan


RADAR Sites
Upper Air Sites
Upper Air Sites (Special)
Field Sites
Hudson Bay
Lake Athabaska
Reindeer Lake
ALBERTA
MANITOBA
SASKATCHEWAN
BERMS
Lake Winnipeg
GPS MOISTURE
ST DENIS NATIONAL WILDLIFE AREA
WEST NOSE CREEK
Lake Manitoba
BRANDON
ADA
CARMAN
FORT PECK

BOREAS Field Site

- Default parameters for soil type, cover etc.
- Drive by atmospheric data
- Measured temperatures, moisture snow

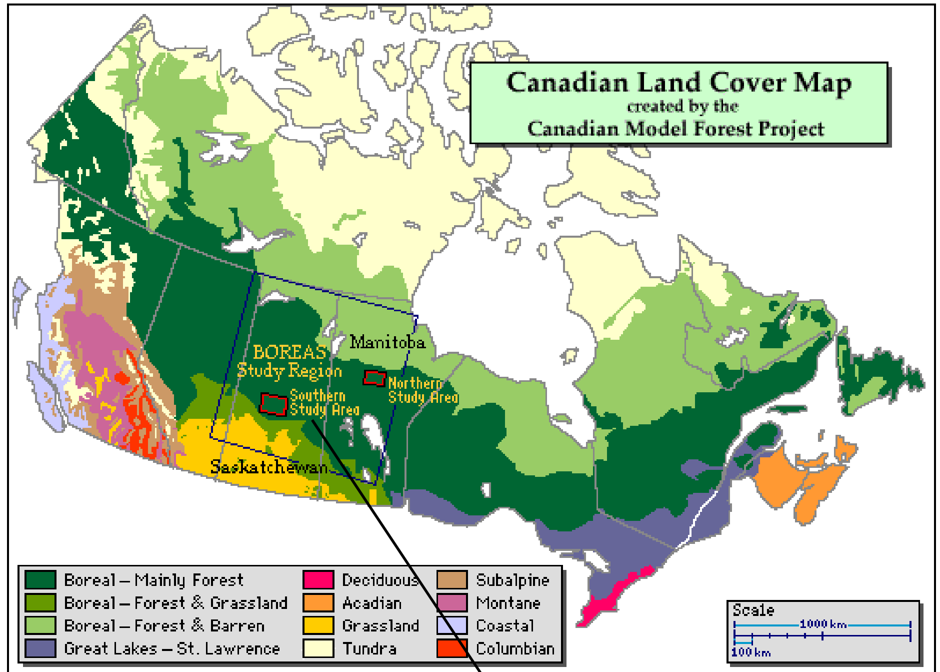
- ❑ Elevation 579.27 m

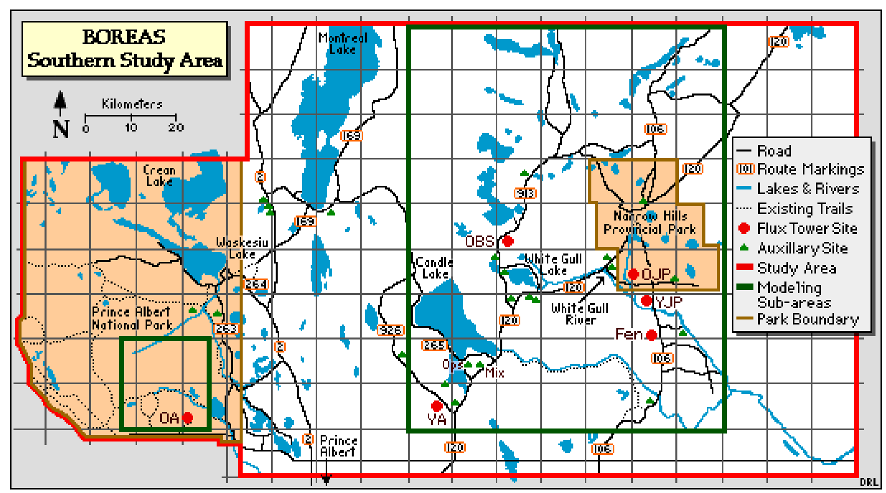
  Mean Annual Air Temp. 0.4° C

- ❑ Mean Total Annual Precipitation 467.2 mm

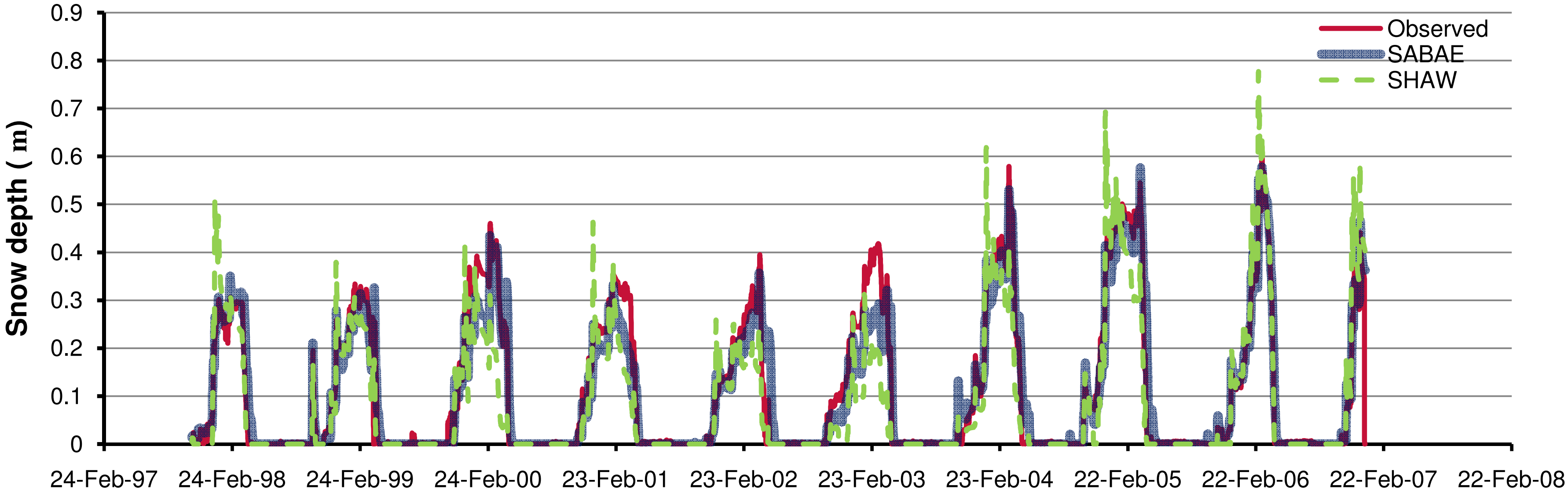
- ❑ Soil type is sand and sandy loam

- ❑ Cover Type mature jack pine, very sparse green alder





Snow Depth



Simulated and measured snow depths from Aug. 1997 to Dec. 2006

Measured data versus SABAE			Measured data versus SHAW		
Average err	RMSE	Correlation	Average err	RMSE	Correlation
-0.007	0.042	0.96	-0.02	0.06	0.90

Average Error, Root Mean Square Error and Correlation values for simulated and measured snow depth within Old Jack Pine site from Aug. 1997 to Dec. 2006

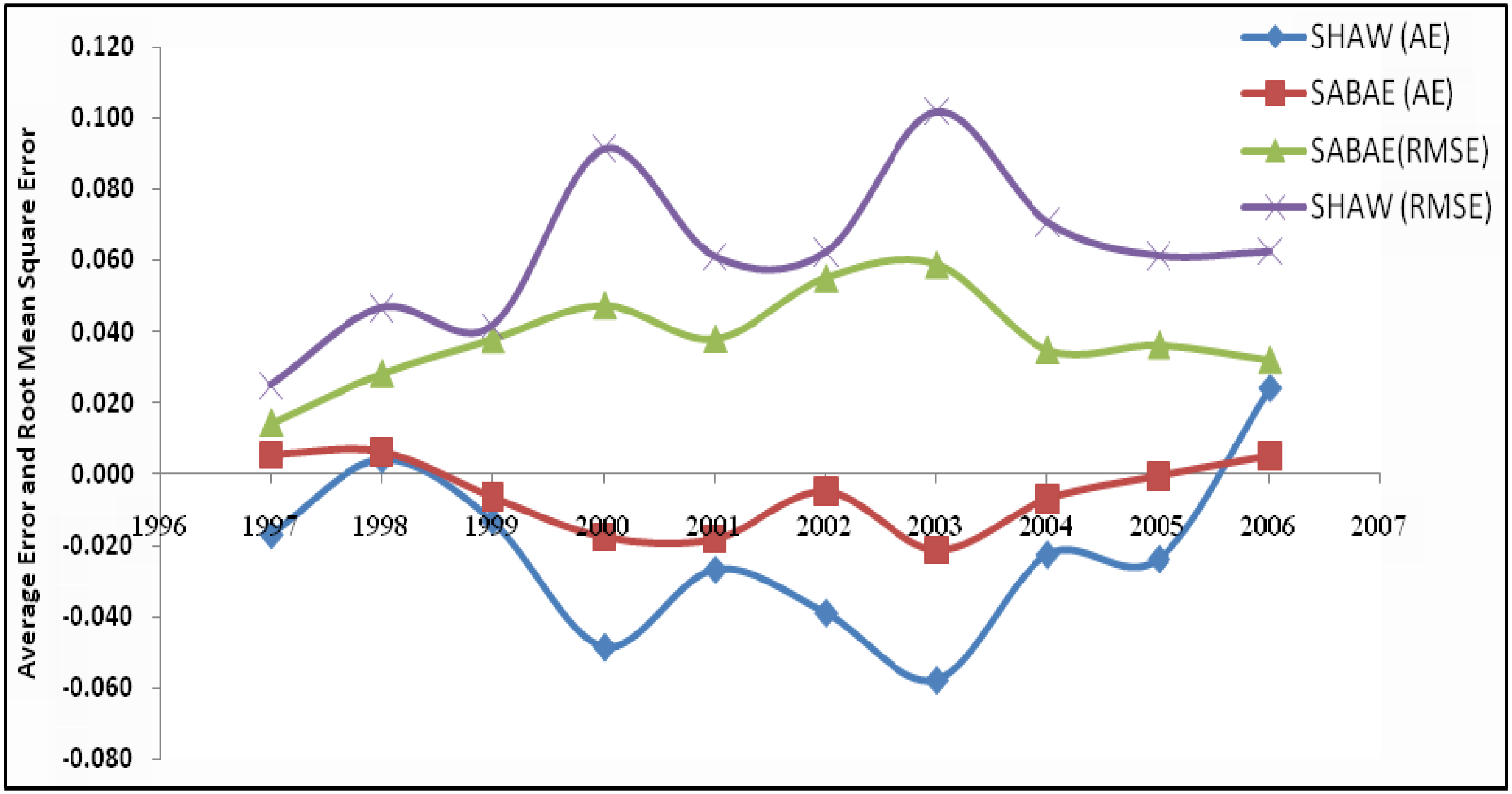
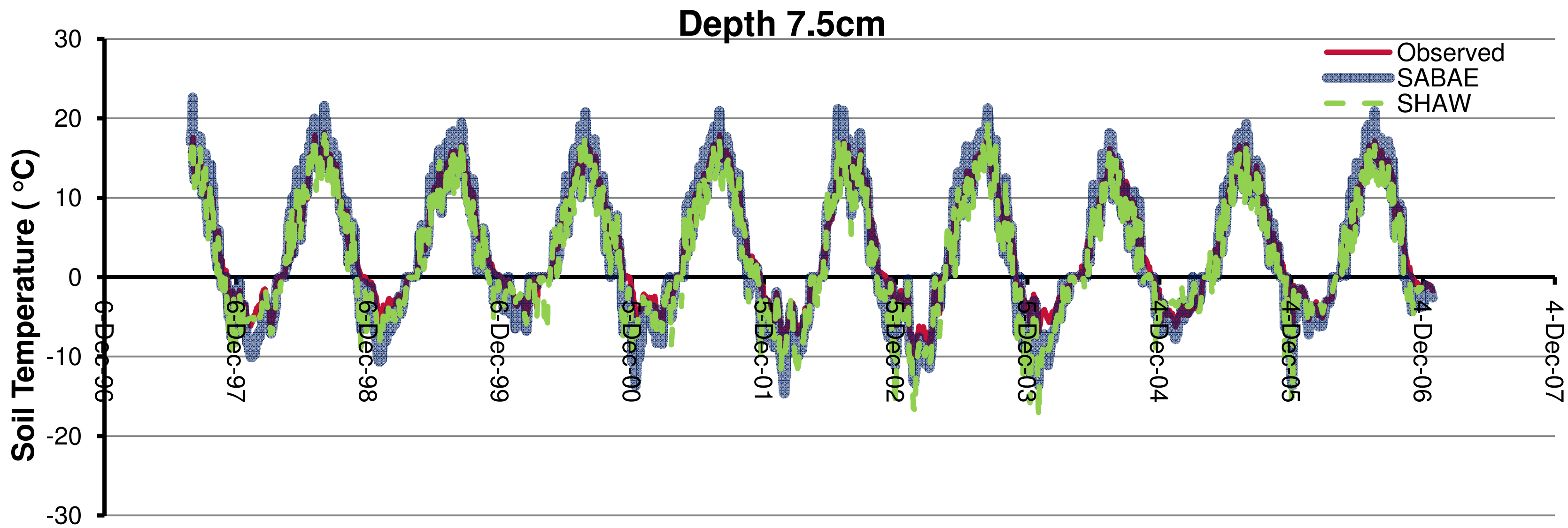
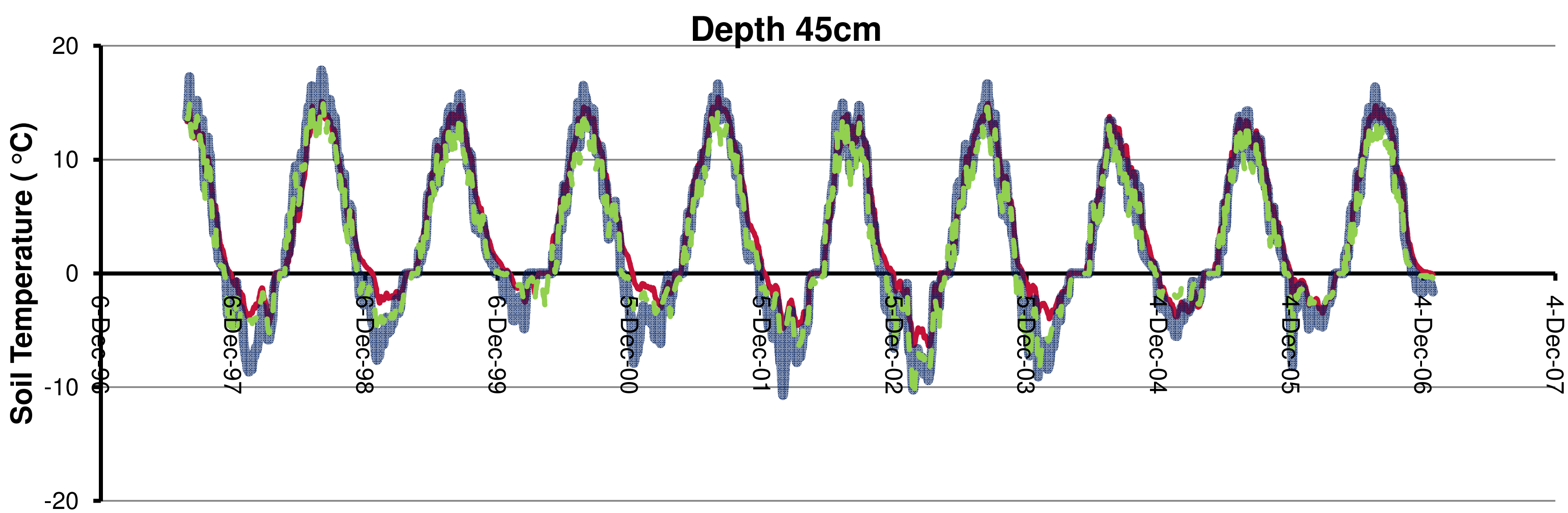
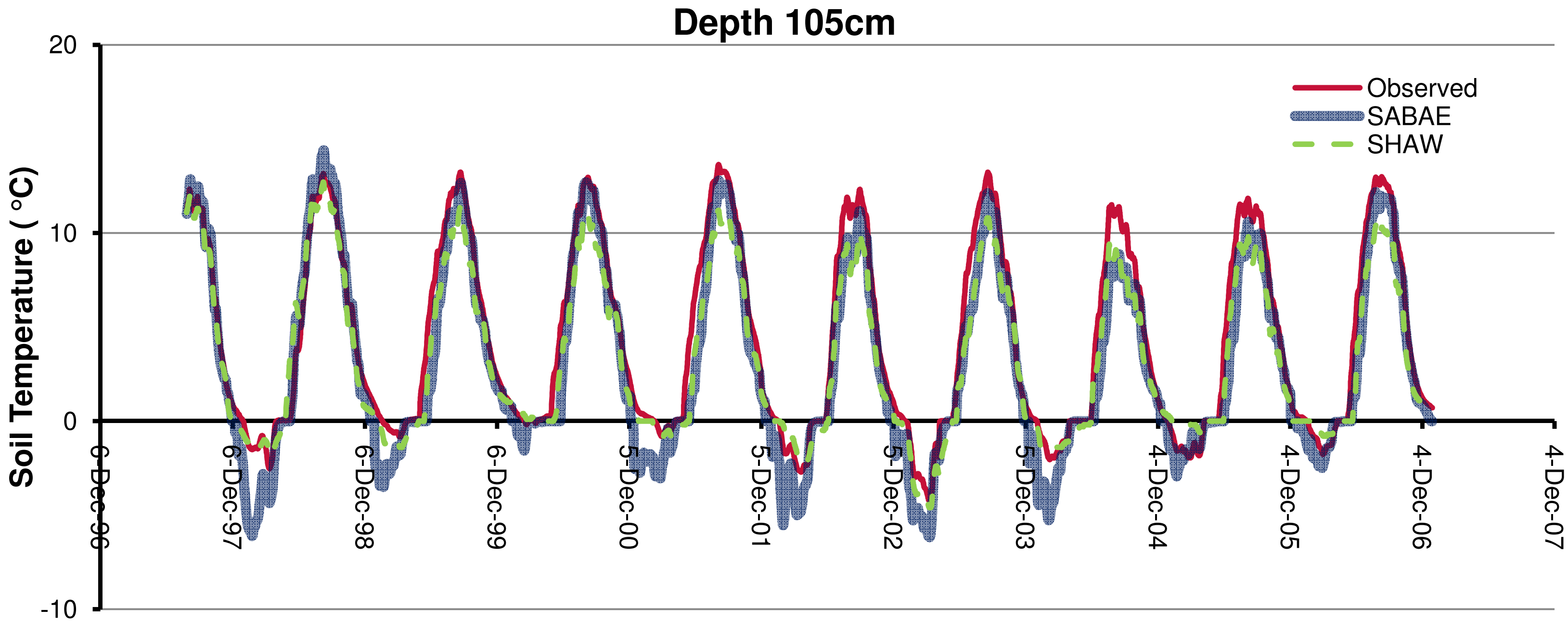


Fig.1. Average Error and Root Mean Square Error for
SABAE and SHAW simulated snow depth from Sep. 1997 to Dec. 2006

Soil Temperature







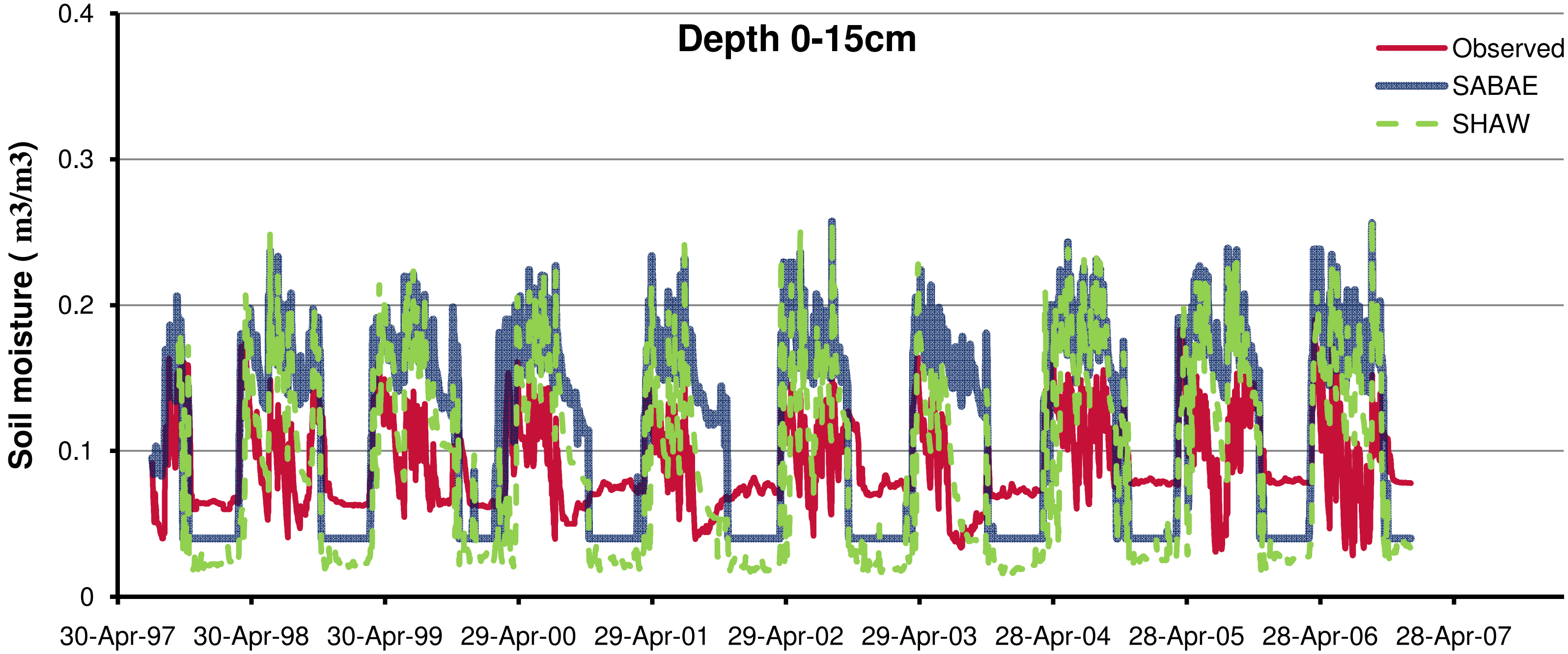
Average Error, Root Mean Square Error and Correlation values for simulated and measured soil temperatures at various soil depths within Old Jack Pine site from Nov. 2004 to Feb. 2005

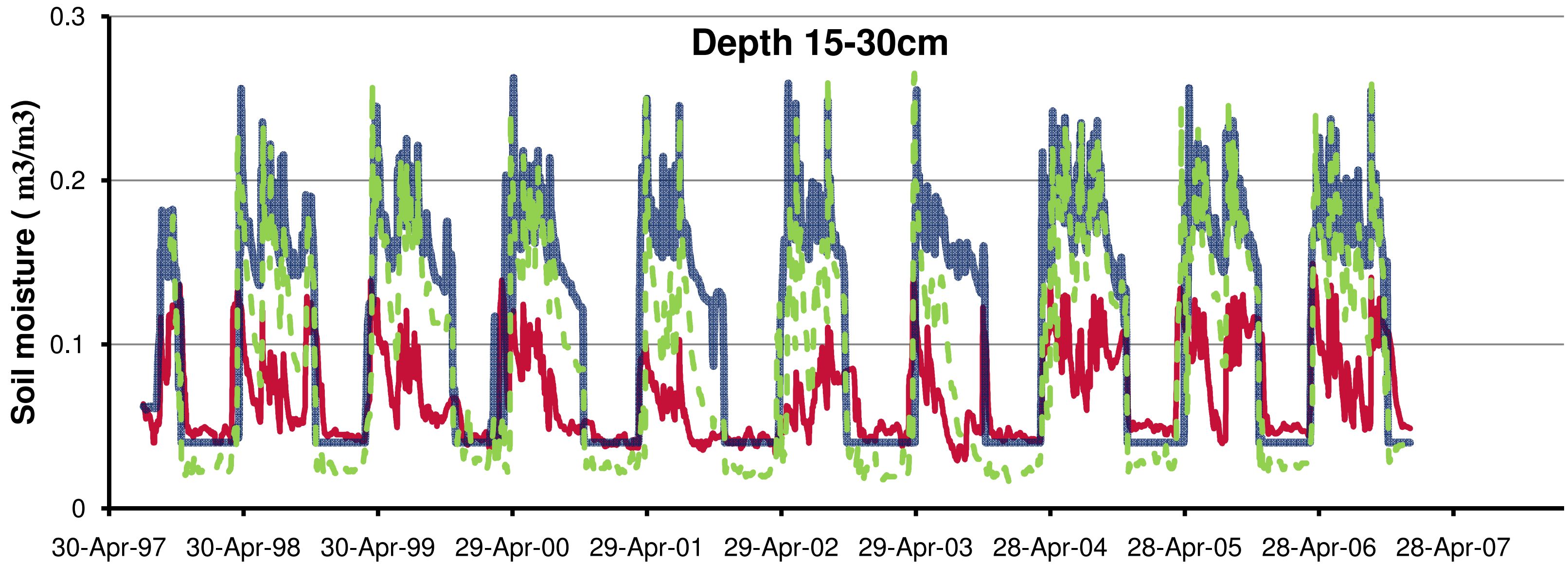
	Measured data versus SABAE			Measured data versus SHAW		
depth	Average err	RMSE	Correlation	Average err	RMSE	Correlation
7.5	-0.70	2.06	0.98	-1.30	2.24	0.97
22.5	-0.80	1.84	0.98	-1.20	1.90	0.97
50	-1.01	1.83	0.98	-1.19	1.68	0.98
100	-1.18	1.30	0.97	-0.96	1.49	0.98

Nov.2004 to Feb. 2005

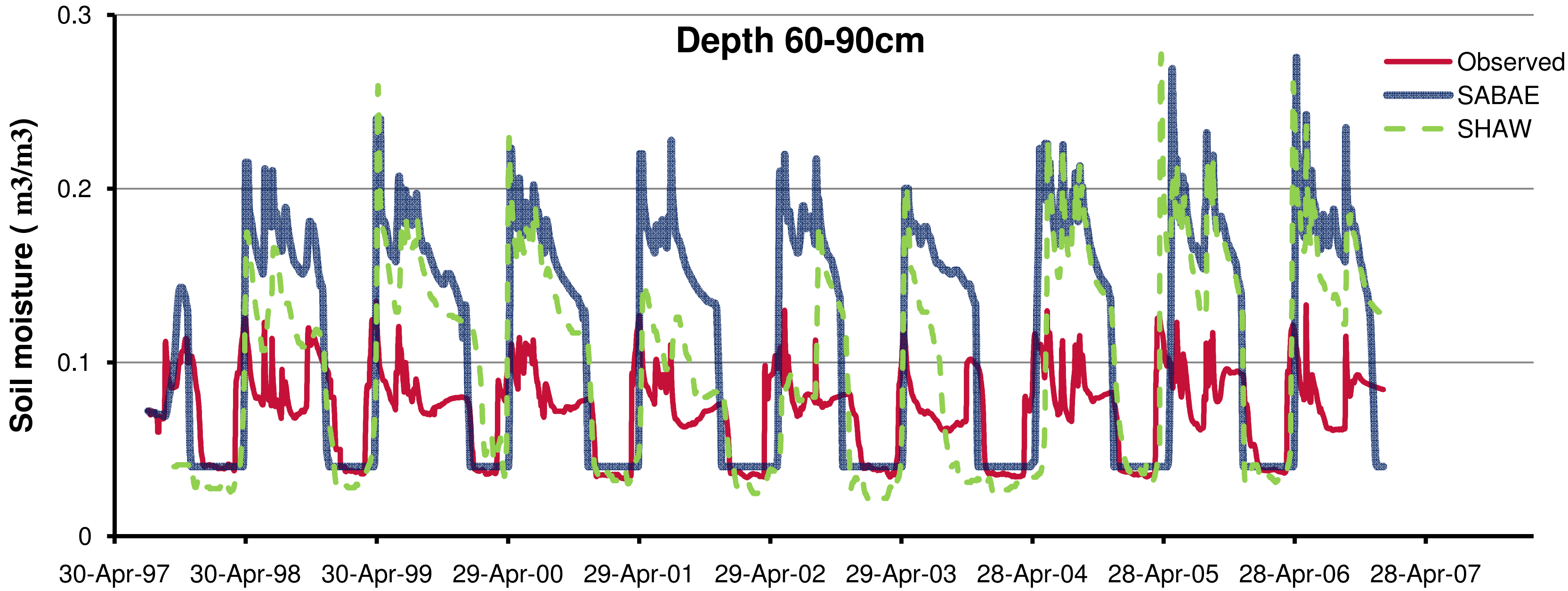
	Measured data versus SABAE			Measured data versus SHAW		
depth	Average err	RMSE	Correlation	Average err	RMSE	Correlation
7.5	-2.11	2.60	**0.90**	-0.7	1.84	**0.66**
22.5	-1.34	1.82	**0.90**	-0.33	1.31	**0.79**
50	0.47	0.91	**0.89**	-0.2	0.91	**0.89**
100	-1.23	1.66	**0.94**	0.7	0.94	**0.97**

Soil Moisture

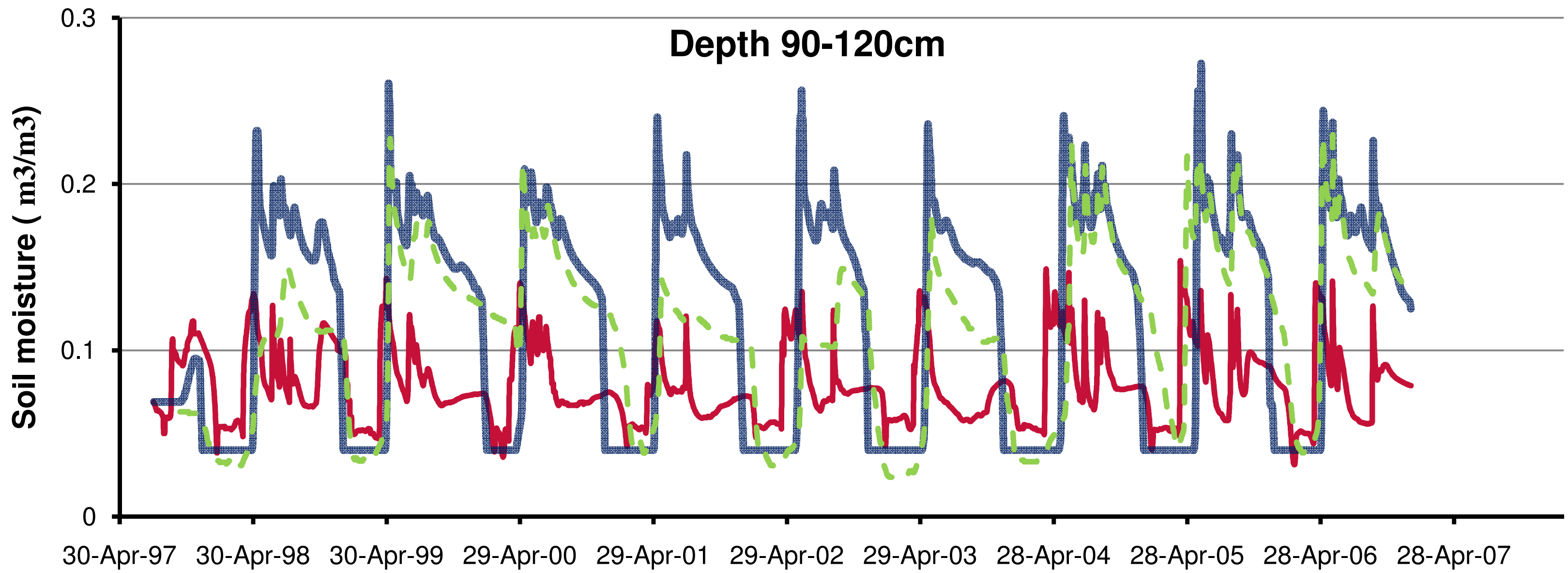




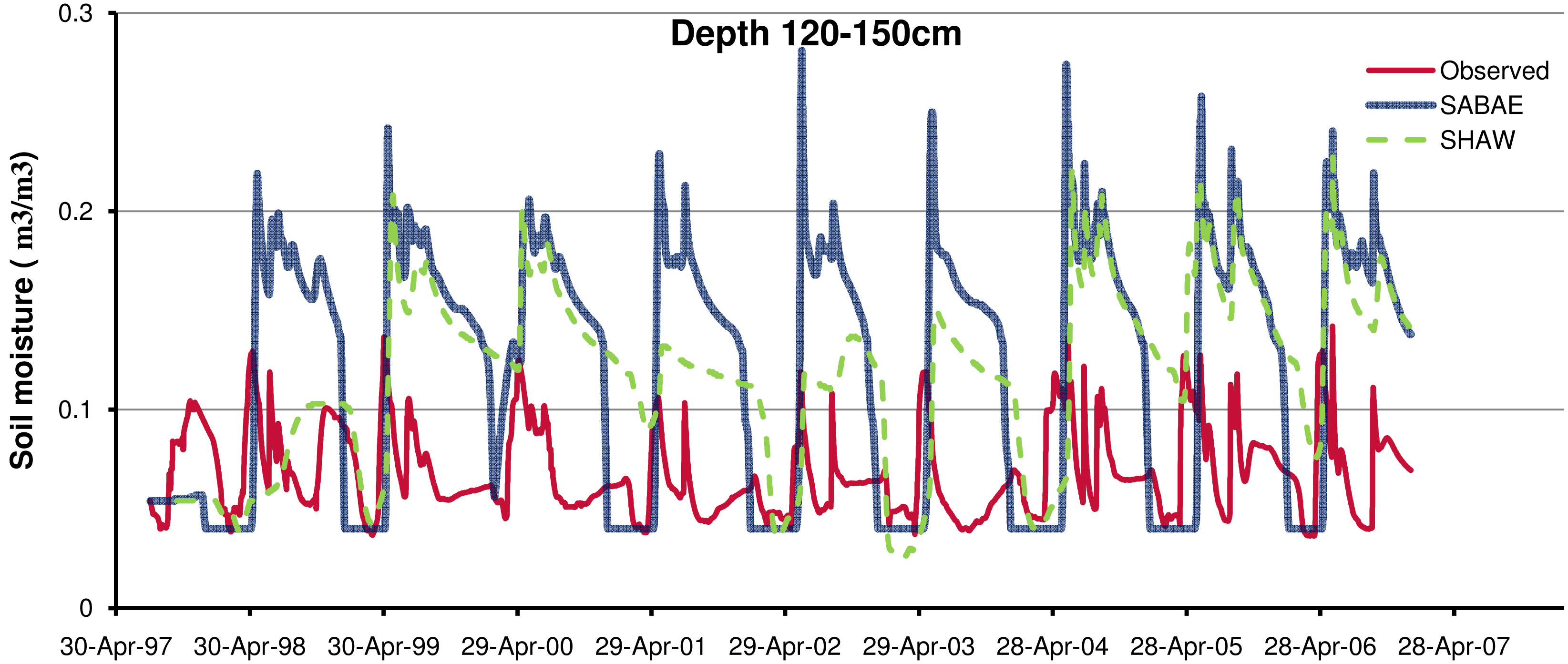
HW-24



Depth 60-90cm
Observed
SABAE
SHAW
Soil moisture (m3/m3)
0.3
0.2
0.1
0
30-Apr-97
30-Apr-98
30-Apr-99
29-Apr-00
29-Apr-01
29-Apr-02
29-Apr-03
28-Apr-04
28-Apr-05
28-Apr-06
28-Apr-07



Depth 90-120cm
Soil moisture (m3/m3)
0.3
0.2
0.1
0
30-Apr-97
30-Apr-98
30-Apr-99
29-Apr-00
29-Apr-01
29-Apr-02
29-Apr-03
28-Apr-04
28-Apr-05
28-Apr-06
28-Apr-07



depth	Measured data versus SABAE Average err	RMSE	Correlation	Measured data versus SHAW Average err	RMSE	Correlation
0-15	0.02	0.06	0.53	0.07	0.10	0.40
15-30	0.04	0.07	0.57	0.06	0.07	0.65
30-60	0.03	0.07	0.40	0.04	0.07	0.30
60-90	0.04	0.07	0.57	0.05	0.07	0.29
90-120	0.03	0.07	0.26	0.05	0.07	0.24
120-150	0.05	0.08	0.17	0.05	0.07	0.14

Average Error, Root Mean Square Error and Correlation values for simulated and measured soil temperatures at various soil depths within Old Jack Pine site from Nov 2004 to Feb 2005

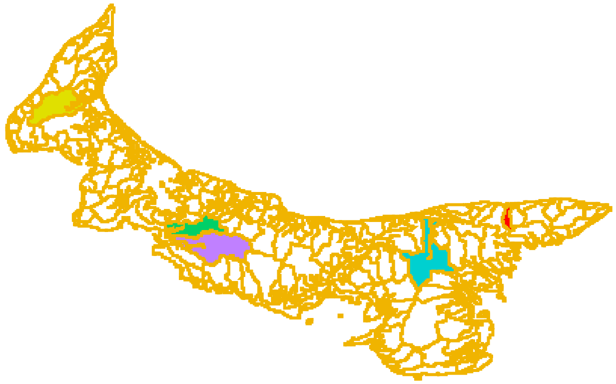
Summary

- Snow depth (when corrected) very good comparisons
- Soil temperature good comparisons
- Soil moisture: apparent bias
  - Macropores
  - Measurement issues

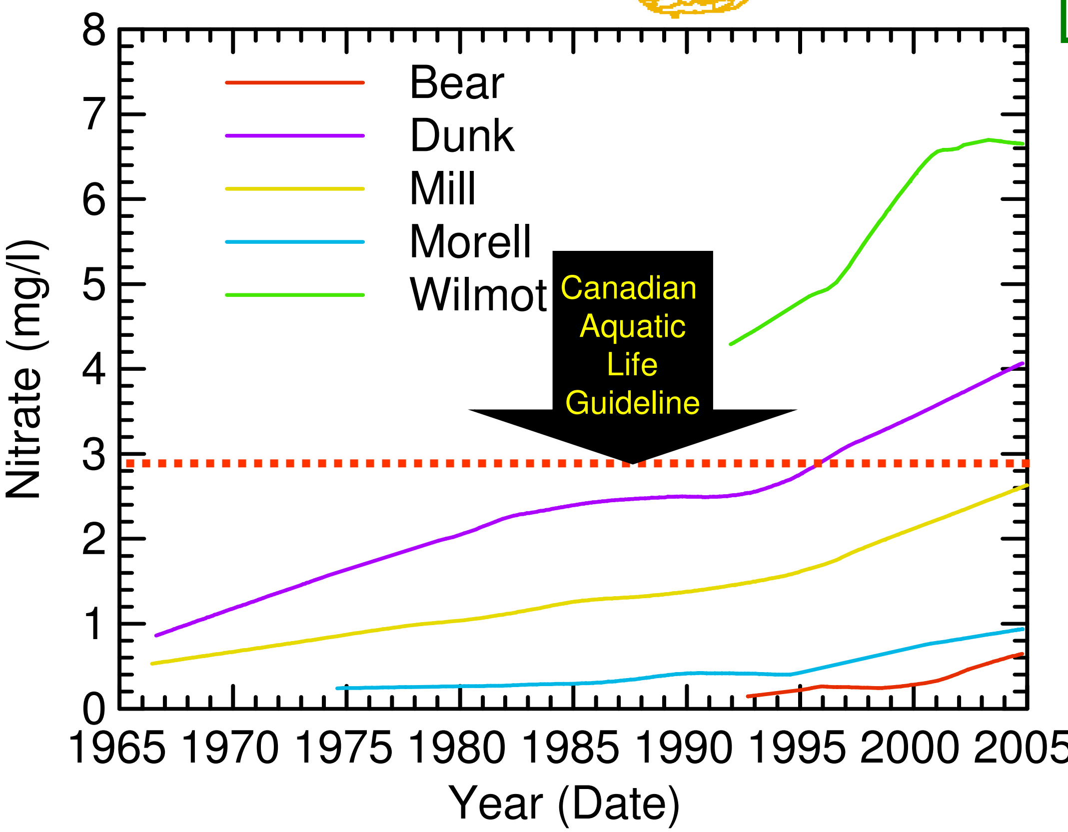
Nitrogen / Carbon Flux

- How to couple to atmosphere?
- Example of large scale nutrient contamination

Surface Water Nitrate Contamination

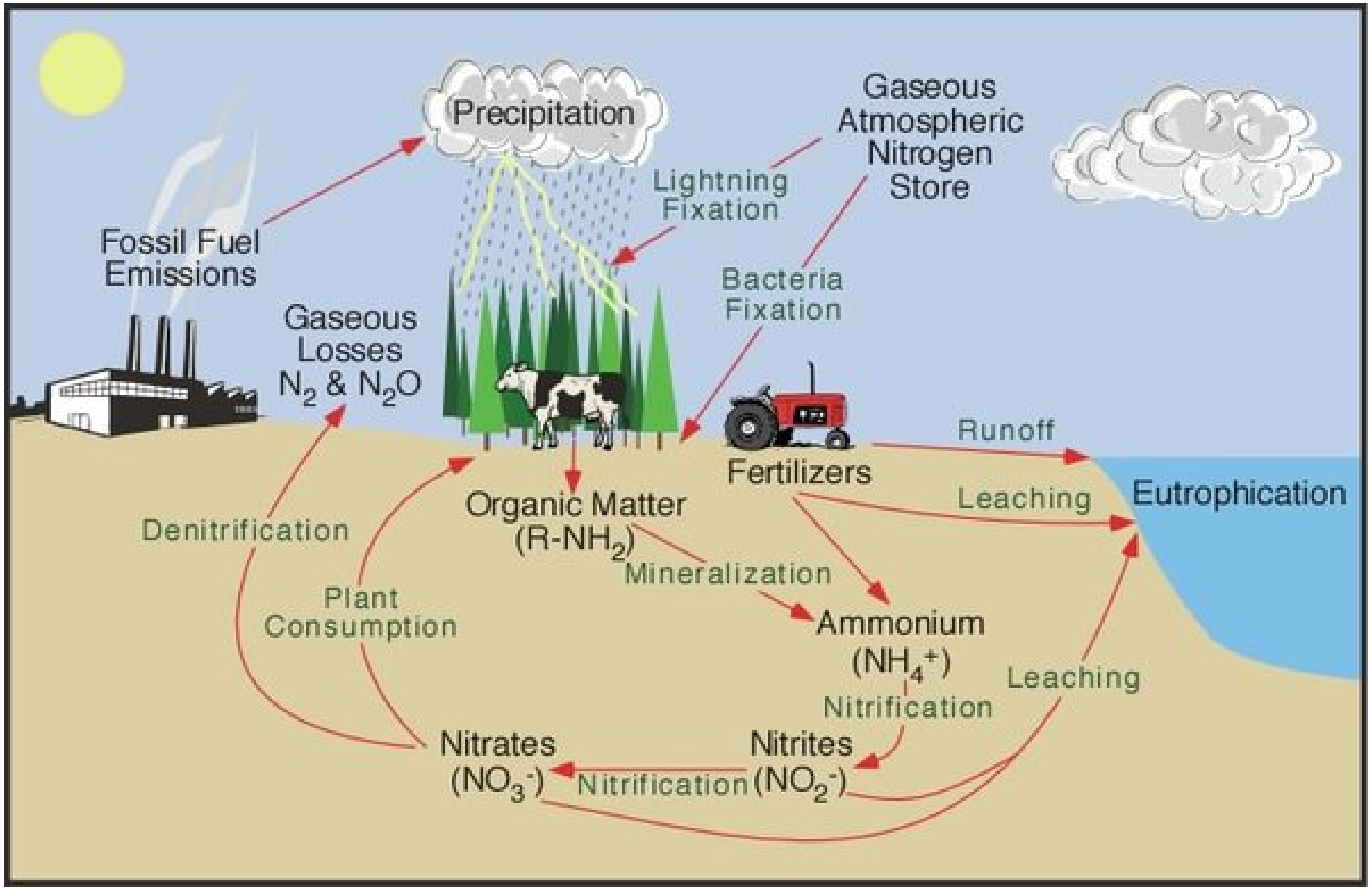


- SW nitrate levels increased over time and exceeded the Canadian aquatic life guideline in some cases.
- Excessive nitrate contributed to eutrophication in some estuaries.



Courtesy of Yefang Jiang, and Jim Young, PEI Provincial sources

Nitrogen Cycle



http://www.physicalgeography.net/fundamentals/9s.html

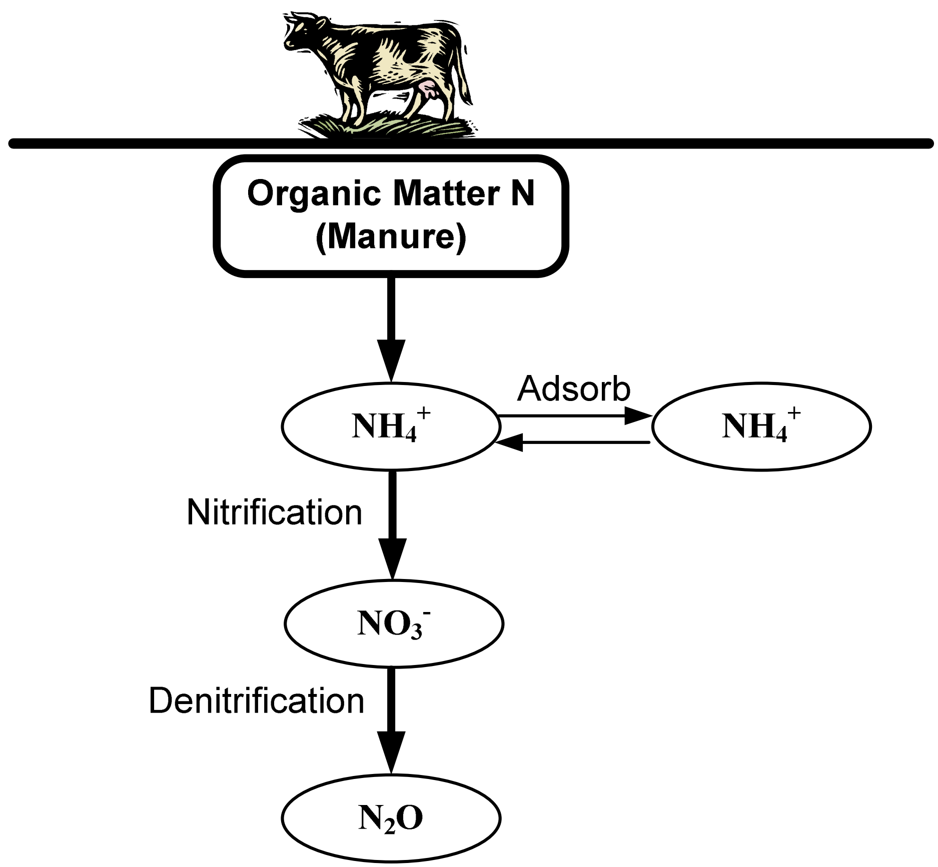
Nitrogen Transport and Transformations Model

Assume here that manure is the only source of organic matter

Single pool nitrogen transformation

NH_4^+ is strongly adsorbed by soil particles

A majority of the leachate nitrogen is in the **NO_3^-** form



Total Processes

- Advection-dispersion, reaction and retardation
- Mass input from land-surface, atmosphere and not some average recharge
- Heat transport, energy fluxes
- Advective fluxes at flow sources/sinks, constant head and river boundaries
- NO_3-N from all sources
- Freeze-Thaw mechanisms

Conclusions

- **SABAE-HW**
  a. Benchmarked and inter-compared
  b. "Verification" with field site atmospheric data
  c. Default values of parameters, minimal calibration
- **Significance**:
  - improved accuracy,
  - better estimates recharge rates to aquifers
  - linkage to groundwater model

Conclusions

- **Outcome**: coupled SABAE with nitrogen biogeochemistry or carbon flux
  a. Study effects of climate on N-cycling
  b. Scale on process model results
  c. Sensitivities to various properties/ parameters.
- **Significance**: Hydrologic synthesis is needed to inform policy makers to deal with challenges of water quality and supply. Important legacy.