Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

IP3
Improved Processes & Parameterisation for Prediction in Cold Regions

Exploring Hydrologic Similarity in the Marmot Creek Basin

http//www.geography.ryerson.ca/wayne/thesis.htm

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Faculty of Engineering & Applied Science

Memorial University

Outline

- Marmot Creek
- Review of Last Years Presentation
- New Data Sources and the need for Hydrologic Similarity
- Topographic Index Calculation
- Evaporative Resistance Simulations using CLASS
- Potential Evapotranspiration Estimation using Penman-Monteith
- TOPMODEL Simulation and Genetic Algorithm Calibration
- Relations between Static Similarity Measures
  land cover vs. topographic index
- Future Work

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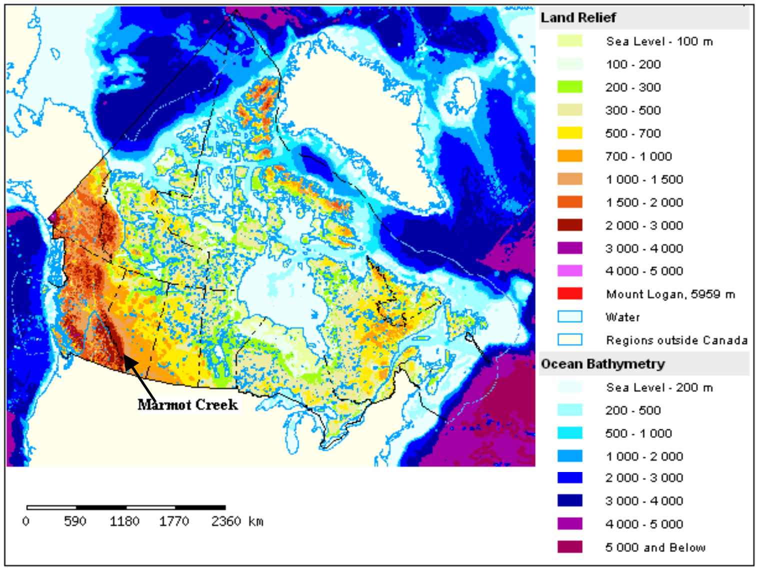
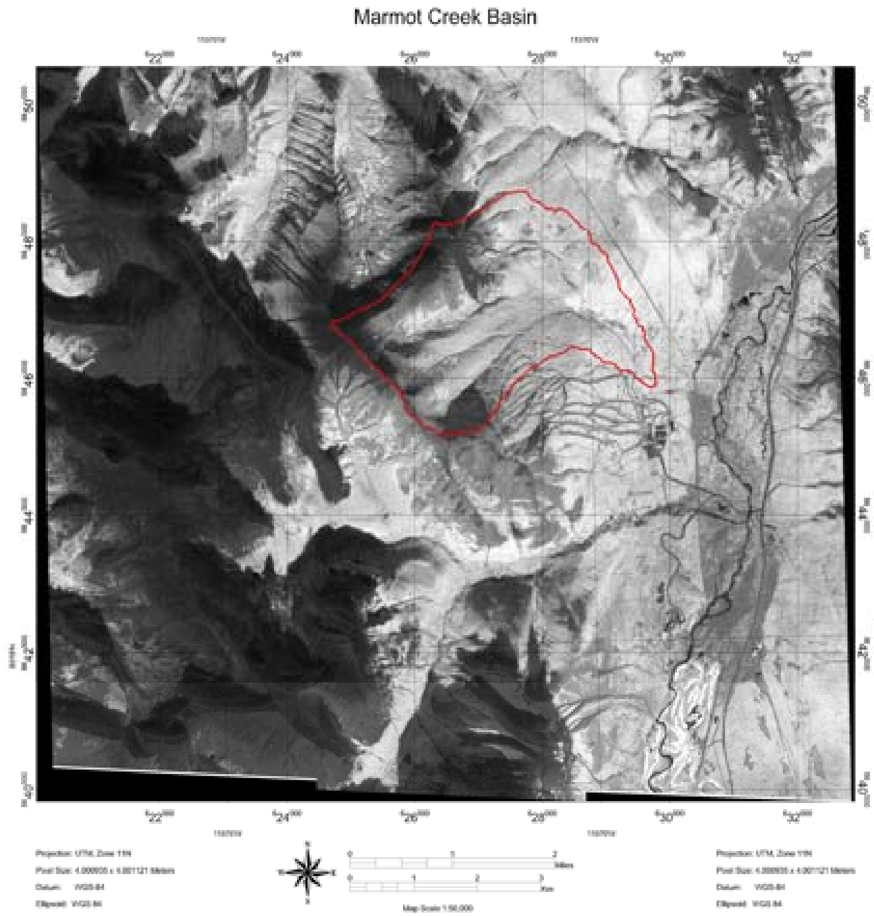
Marmot Creek Basin



- **Located at latitude 50°57'N and longitude 115°10'W**
- **About 110km southwest of Calgary**

Marmot Creek Basin

- **Total area : 9.5km^2**
- **Elevation: 1585-2805m, the mean value is 2112m, the difference of elevation is 1220m**



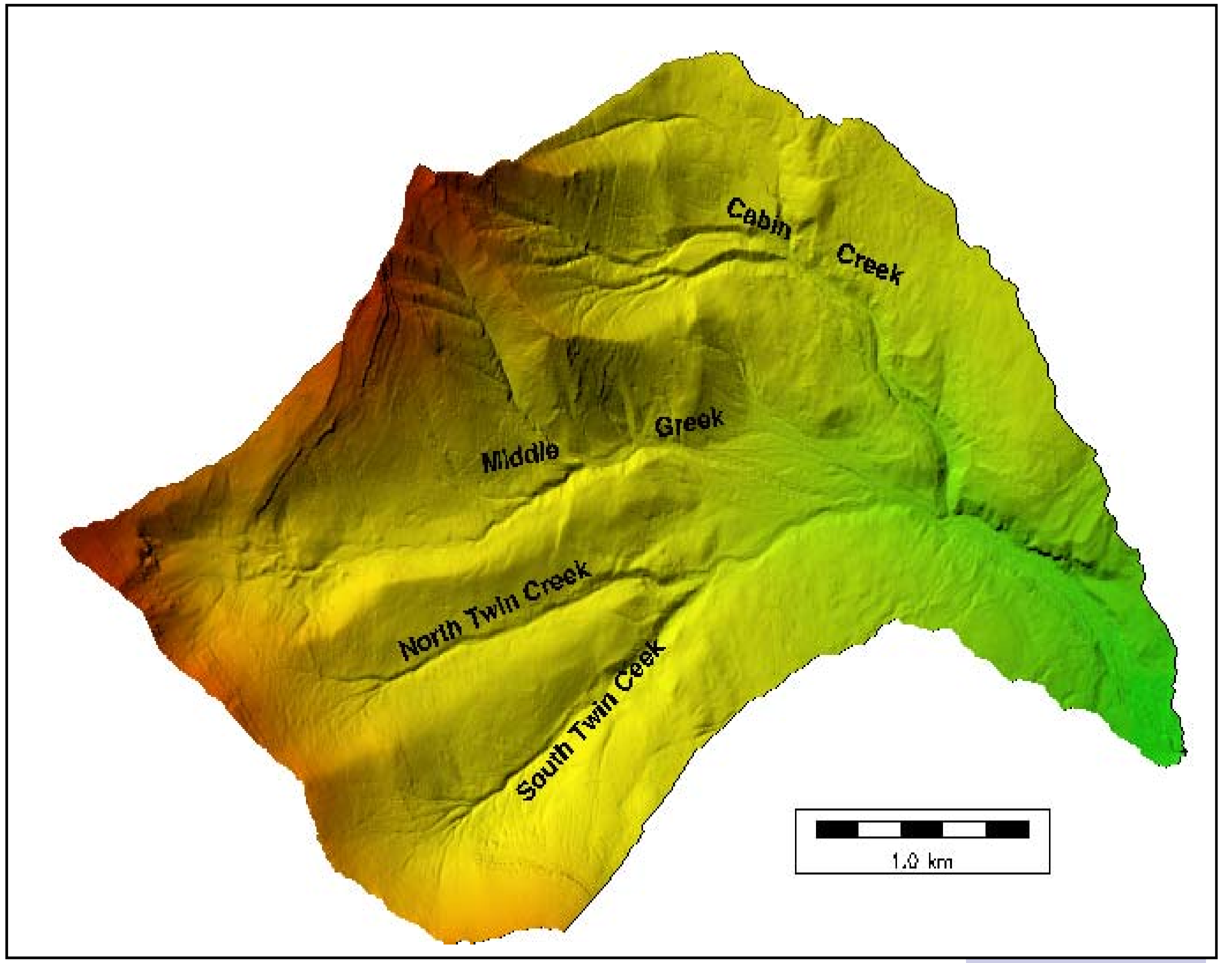
Marmot Creek Basin

- **Three sub-basins:**

  Twin Creek

  Middle Creek

  Cabin Creek



Marmot Creek Basin

- **Forest Cover: 60%**
- **Soil types:** Brunisolic Grey Wooded Soils, podzolic soils, regosolic soils, alpine black soils, local gleysolic and organic soils (Stevenson, 1967(thesis))
- **Climate Characteristic:**

  Mean annual precipitation—1080mm

  Average July temperature— 2 to 18°C

  Average January temperature — -6 to -18°C
- **Streamflow Characteristic:**

  Groundwater is the main source

  In midsummer, 70% derived from snow melting

  Mean Annual Runoff = 425 mm

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Data Collection

- **Topographic Data**

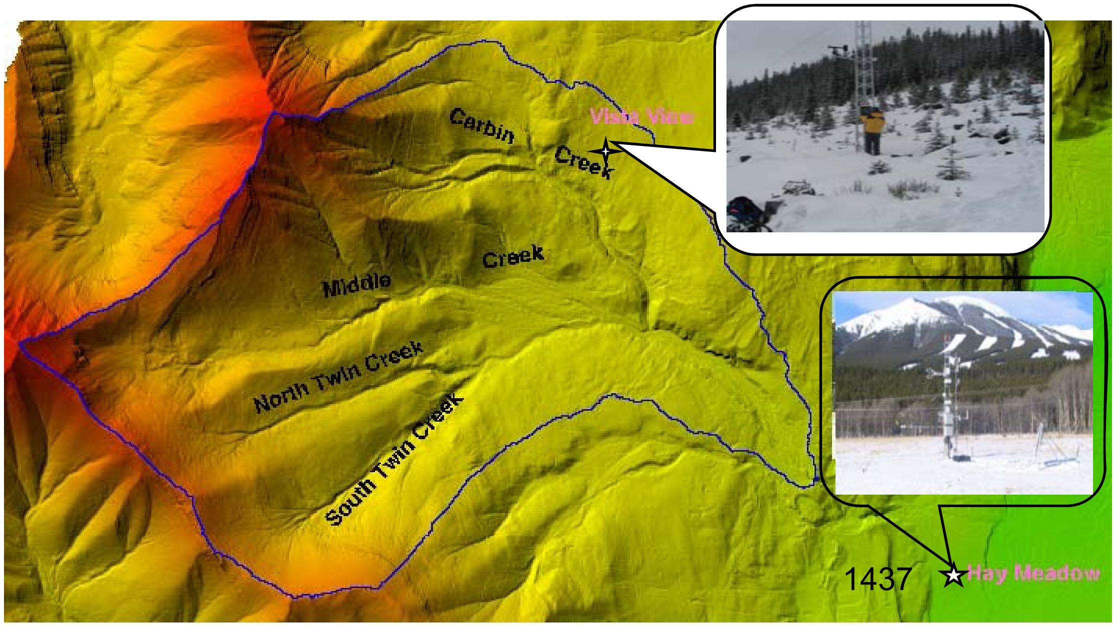
  Shuttle Radar Topography Mission (SRTM) data– 90m

  Light Detection and Ranging (LiDAR) data – 1m

- **Meteorological Data**

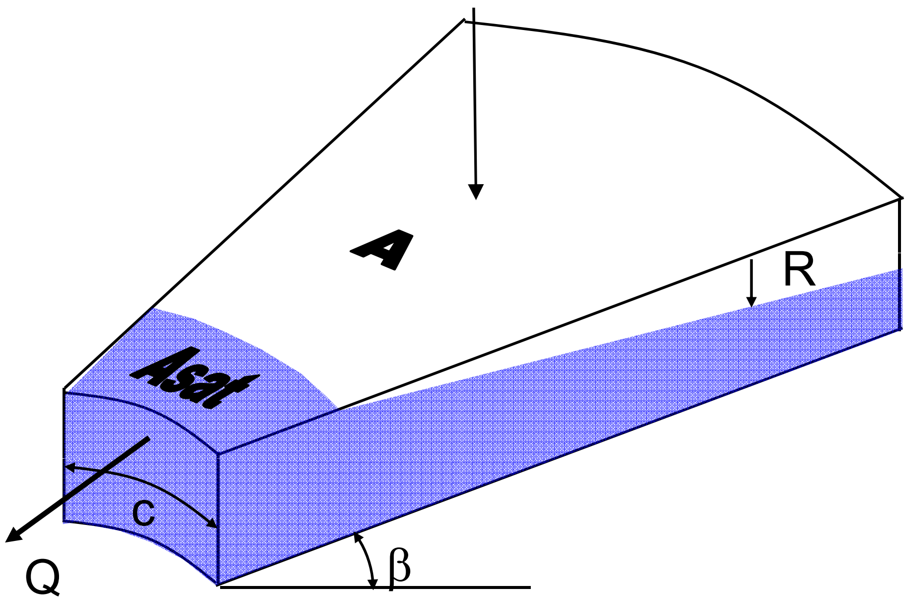
  Hay Meadow Station

  Vista View Station



Last Year in Review

TOPMODEL



Continuity:

$$I - O = \frac{dS}{dt} = 0 \quad \text{(Steady Assumption)}$$

$$AR - Q = 0$$

$$Q = AR$$

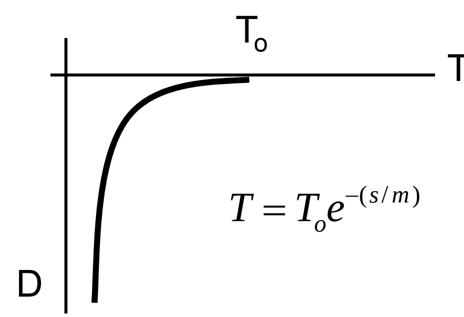
Darcy's Law:

$$q = K\frac{dh}{dx}$$

$$q(Dc) = K(Dc)\tan(\beta)$$

$$Q = Tc\tan(\beta)$$

Transmissivity vs Depth



s - soil moisture deficit

Problems:

- Precipitation Uniform
- Instantaneous Redistribution

Last Year in Review

$$AR = Q = Tc\tan(\beta)$$

$$\frac{AR}{c\tan(\beta)} = T_o e^{-(s/m)} \qquad a = \frac{A}{c} \quad \text{flow accumulation}$$

$$\frac{Ra}{T_o\tan(\beta)} = e^{-(s/m)}$$

$$s = -m\left[\ln\left(\frac{R}{T_o}\right) + \ln\left(\frac{a}{\tan(\beta)}\right)\right] \qquad \ln\left(\frac{a}{\tan(\beta)}\right) \text{ - Topographic Index}$$

$$\bar{s} = -m\left[\ln\left(\frac{R}{T_o}\right) + \lambda\right] \qquad \lambda \text{ - Average Topographic Index}$$

Simple Algebra

$$s_i - \bar{s} = -m\left[\ln\left(\frac{a}{\tan(\beta)}\right)_i - \lambda\right]$$

known from DEM

TOPMODEL
Linear Redistribution Equation ☺

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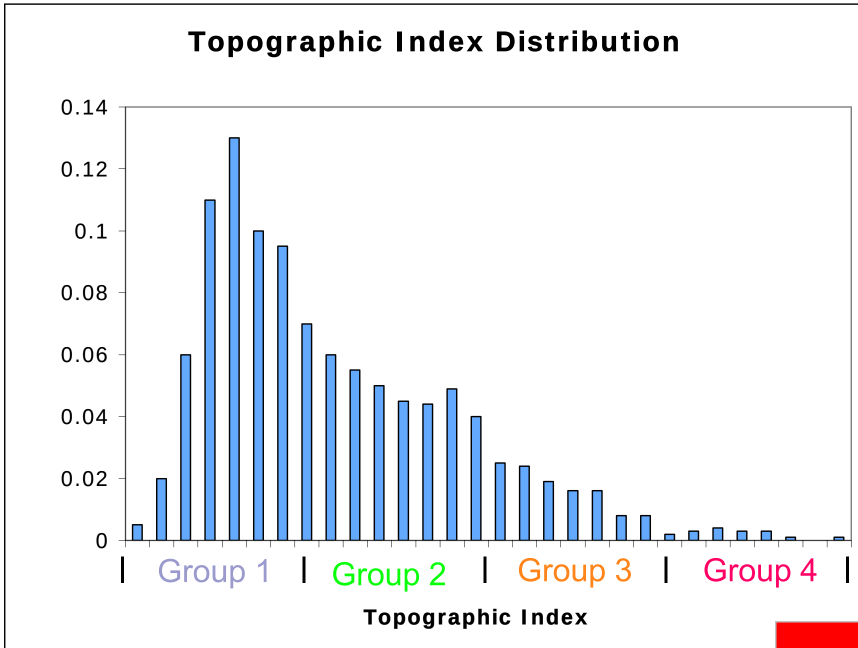
Last Year in Review

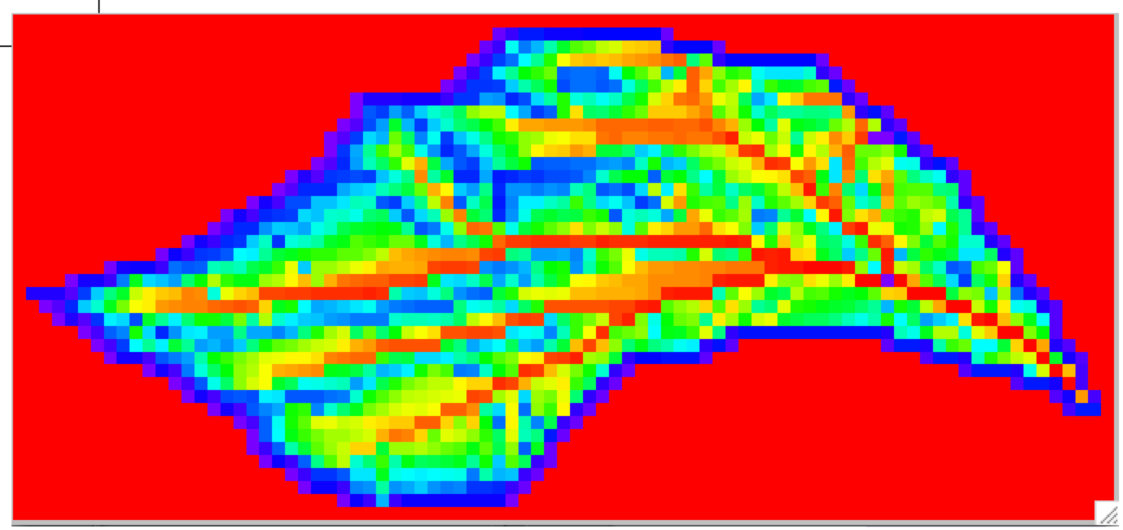


Hydrologic Similarity via Slope Position

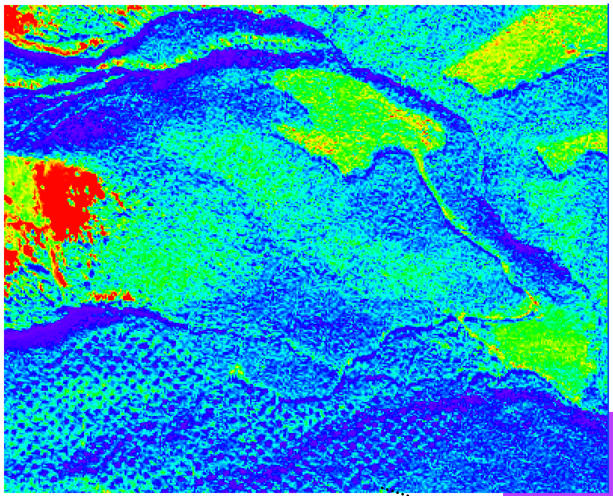
Moisture Distribution via Average Storage

Measurable Parameters [T_o, m, ln(a/tan(β))]

Topographic Index
Marmot Creek

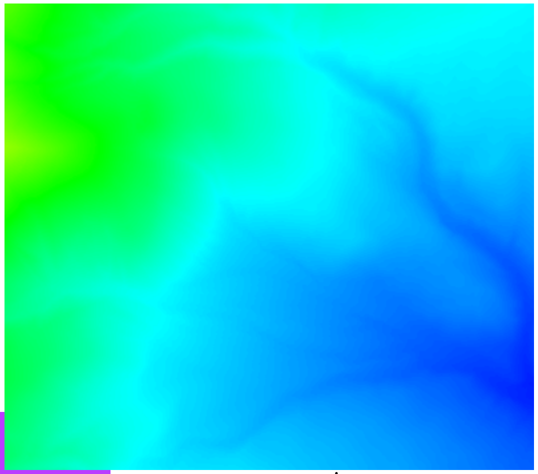


Need For Hydrologic Similarity

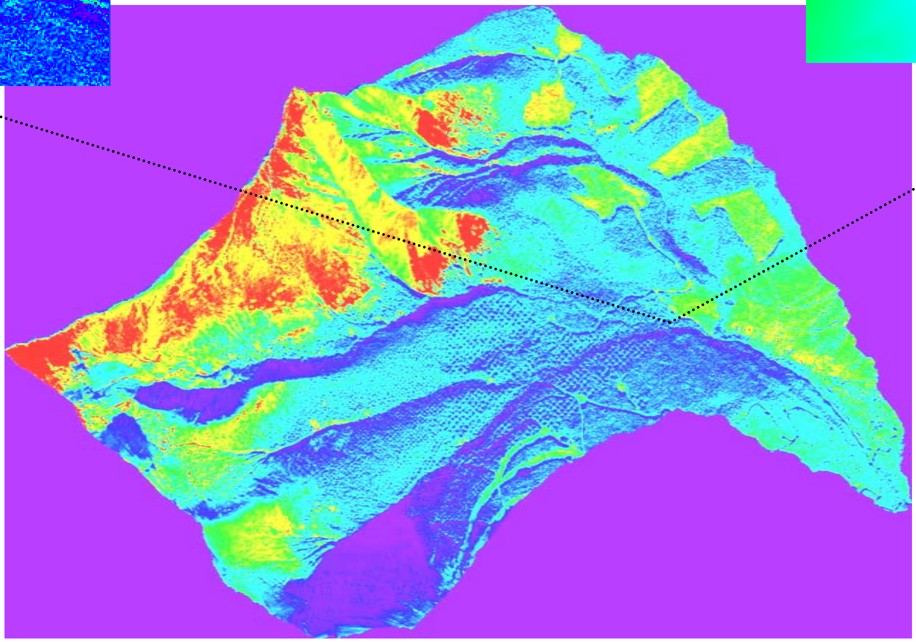


4 m Land Cover

How will we summarize and utilize all the spatial data?



1 m Topography



Topographic Index

- **What is topographic index?**

  ln(a/tanβ)

  a is specific contributing area

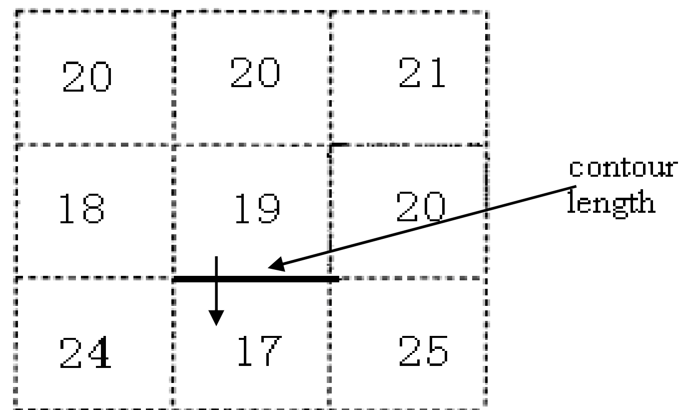
  tanβis ground surface slope

- **Flow routing algorithms**

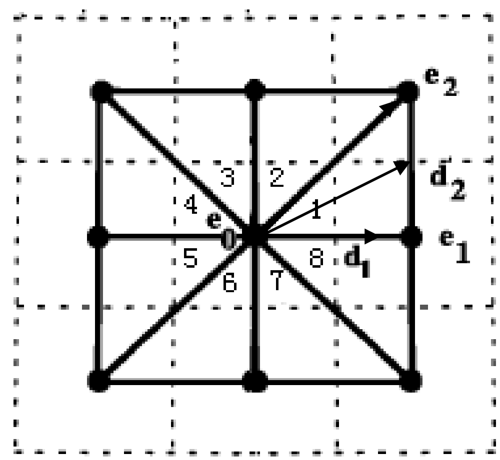
  Single flow direction algorithm(D8)

  Biflow direction algorithm (D∞)

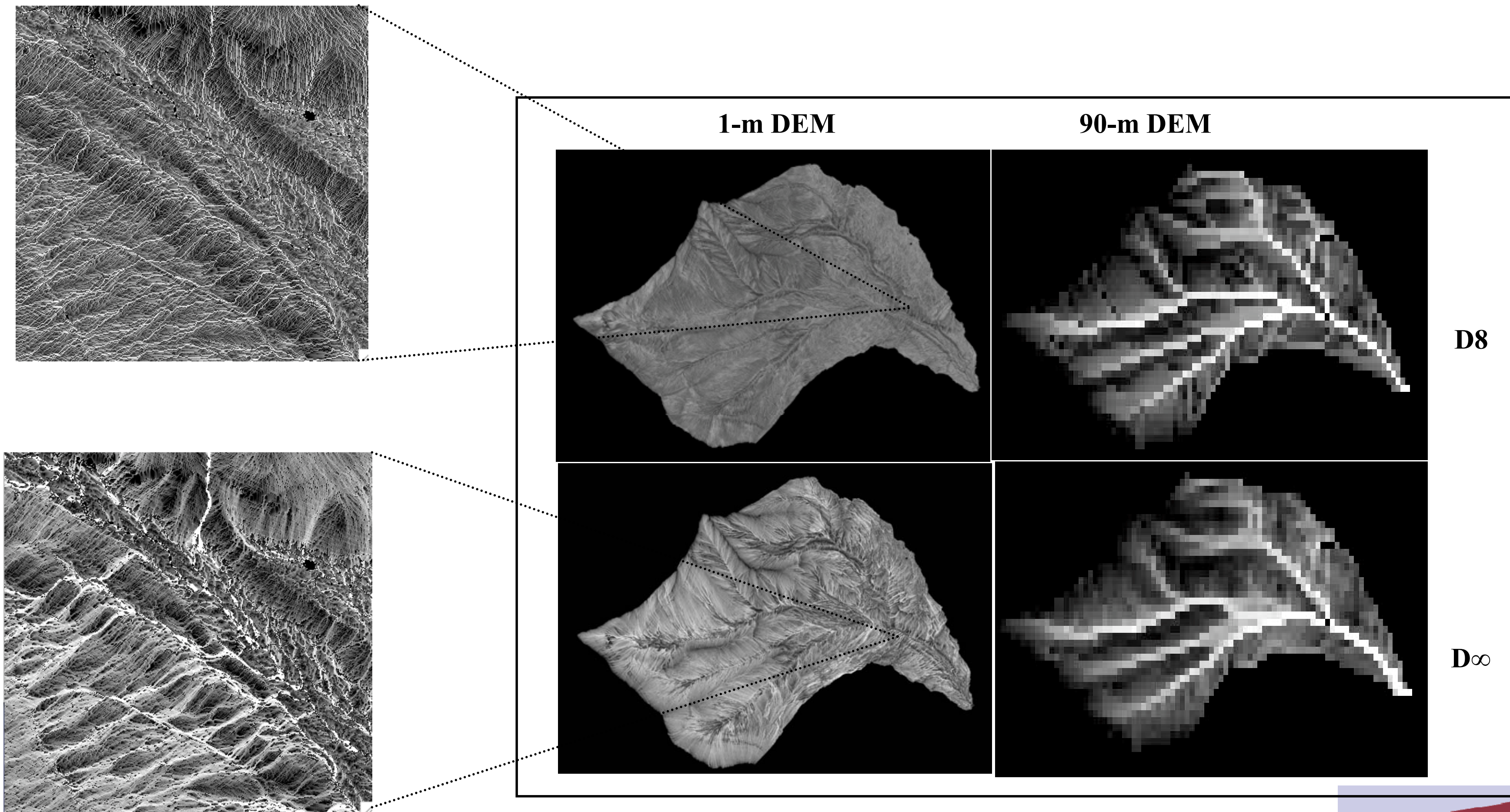
D8



D∞

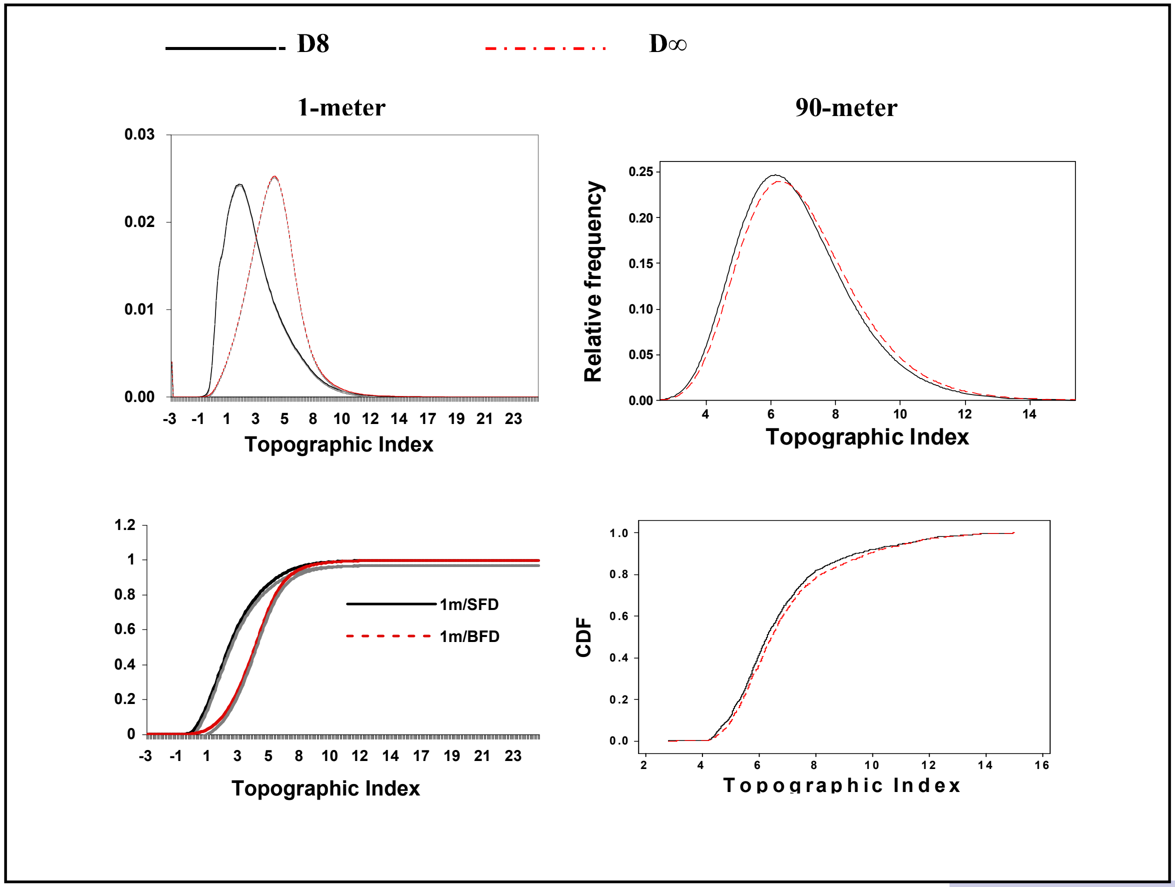


Topographic Index Results



Topographic Index Results

- Frequency Distributions of ln(a/tanβ)
- No big difference between 90-meter resolution DEM
- The discrepancy of 1-meter resolution is obvious



Topographic Index Results

Grid Size	Algorithm	Variable	Mean
90-meter	D8	In(a/tan β)	6.77
	D∞	In(a/tan β)	6.95
1-meter	D8	In(a/tan β)	3.05
	D∞	In(a/tan β)	4.50

- **D8 → D∞ In(a/tanβ) ↑**
- **1-meter → 90-meter DEM In(a/tanβ) ↑**

CLASS & Resistance Calcs

- **What is CLASS?**

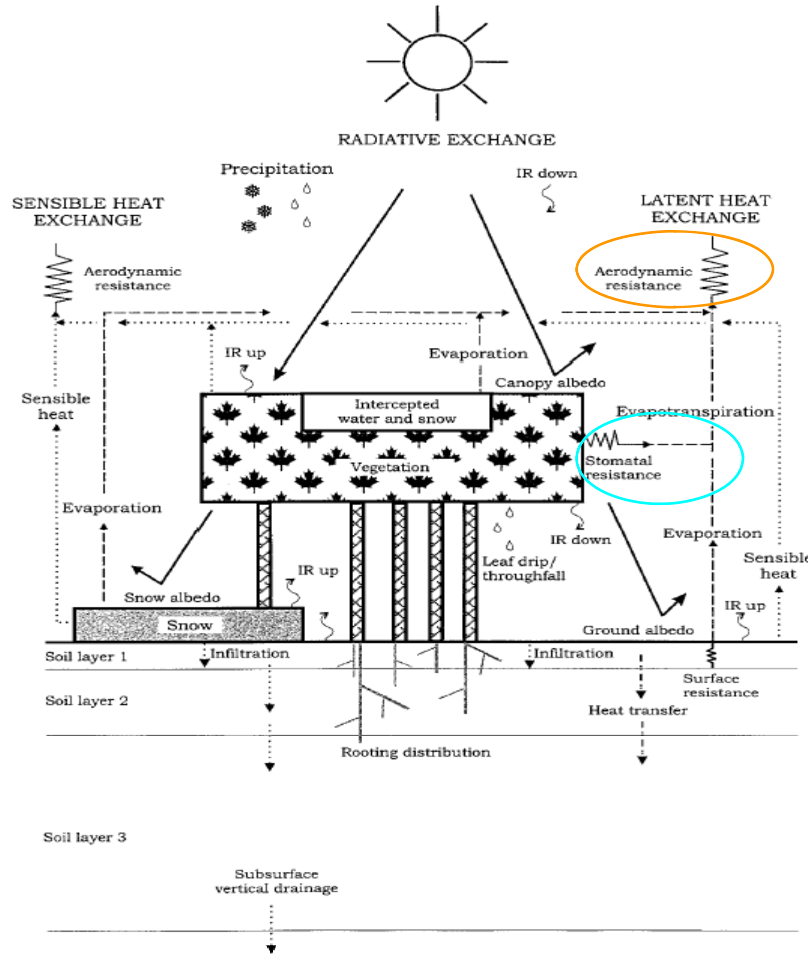
  Canadian Land Surface Scheme is first developed in 1987 at the Meteorological Service

- **What is the aim of CLASS**

  To simulate the energy and water balances of vegetation, snow and soil

- **What is the objective of CLASS simulation in this study?**

  To simulate stomatal resistance and aerodynamic resistance



Schematic diagram of CLASS (from Verseghy, 2000)

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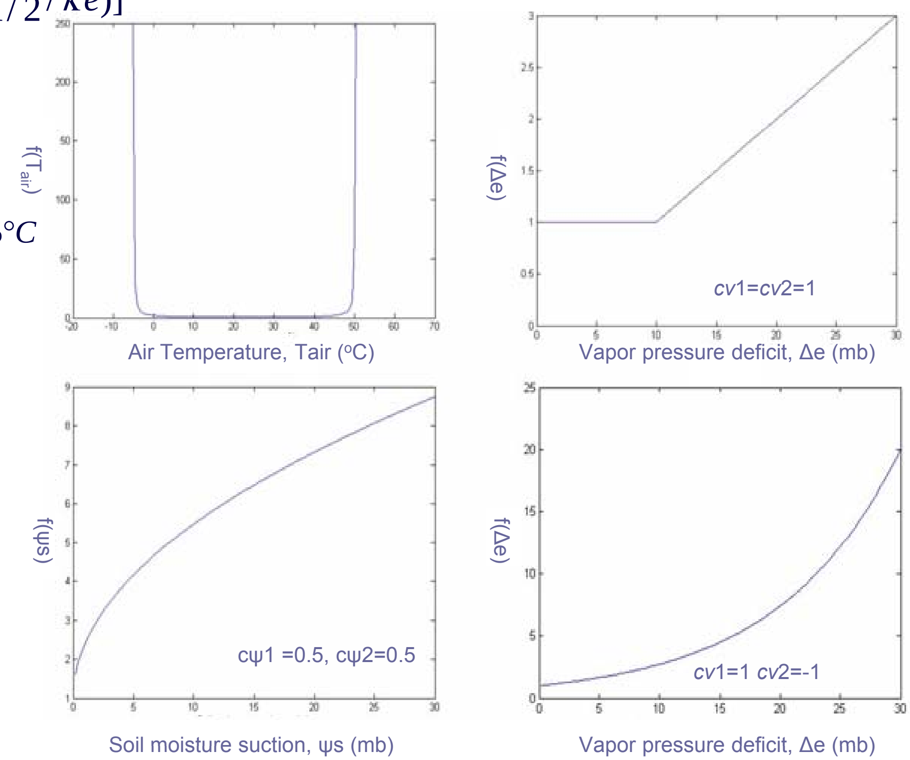
Stomatal Resistance

- **Stomatal resistance is estimated as:**

$$r_{c,i} = f_1(T_{air})\, f_2(\Delta e)\, f_3(\psi s)\, r_{c,u,i}$$

$$r_{c,u} = r_{s,\min} \kappa e / \ln[(K\downarrow + K\downarrow_{1/2}/\kappa e)/(K\downarrow \exp(-\kappa e \Lambda) + K\downarrow_{1/2}/\kappa e)]$$



$$f_1(T_{air}) = 1.0 \qquad 5°C \le T_{air} \le 40°C$$

$$= 250.0 \qquad T_{air} \ge 50°C, or, T_{air} \le -5°C$$

$$= 1.0/[1.0 - (5.0 - T_{air}) \times 0.1] \qquad -5°C < T_{air} < 5°C$$

$$= 1.0/[1.0 - (T_{air} - 40.0) \times 0.1] \qquad 40°C < T_{air} < 50°C$$

$$f_2(\Delta e) = (\Delta e / 10.0)^{cv2/cv1} \qquad cv2 > 0$$

$$= 1/\exp(-cv1 \Delta e / 10.0) \qquad cv2 \le 0$$

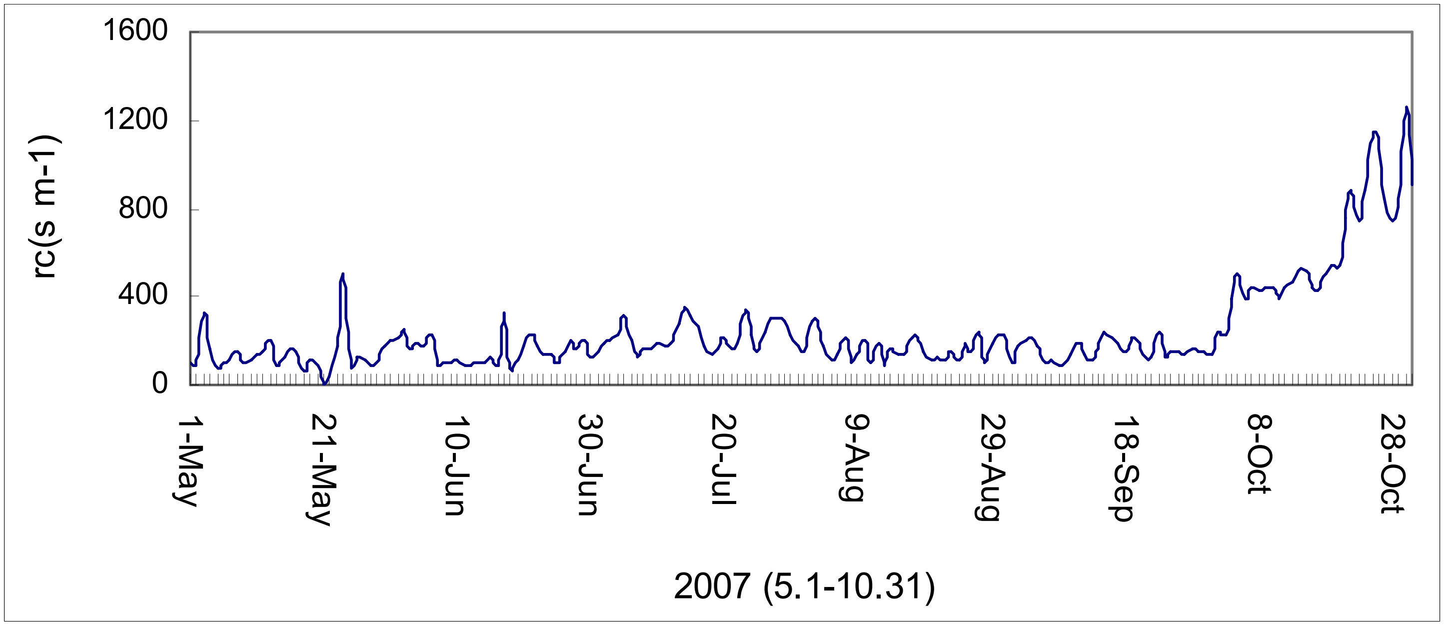
$$f_3(\psi s) = 1 + (\psi s / c_{\psi 1})^{c \psi 2}$$

$$= 1$$

For PET Calculation

Stomatal Resistance Results

- The estimate of stomatal resistance



- Period from 9:00 a.m. to 5:30 p.m.
- Low in May-September, High in October
- Mean value is 267 s m^{-1}

Aerodynamic Resistance

- **What is aerodynamic resistance (r_a)?**

  The resistance encountered by fluxes of water vapor or heat or momentum along the path of transfer, which is from the source to a given reference air level above

- **How does CLASS determine aerodynamic resistance?**

$$r_a = \frac{1}{C_D v_a}$$

Where C_D is the surface drag coefficient, and v_a is the wind speed

Aerodynamic Resistance (cont'd)

- **How to determine drag coefficient for heat and water vapour fluxes $C_{D,E}$?**

$$C_{D,E} = \left[\frac{k}{\ln\left(\frac{z_m - z_d}{z_{0,E}}\right)} \right] \left[\frac{k}{\ln\left(\frac{z_m - z_d}{z_{0,M}}\right)} \right] \Phi_E \Phi_M$$

Where z_m (m) is the reference height; z_d (m) is the zero-plane displacement; k=0.04 is von Karman's constant; $z_{0,M}$ (m) is the roughness length for momentum transfer; $z_{0,E}$ (m) is the roughness length for heat or vapor pressure transfer; Φ_M and Φ_E are stability correction factors.

Aerodynamic Resistance (cont'd)

- **Is there another method to determine aerodynamic resistance?**

$$r_{ah0} = \frac{\left[\ln\left(\frac{z_m - z_d}{z_0}\right)\right]^2}{k^2 v_a}$$

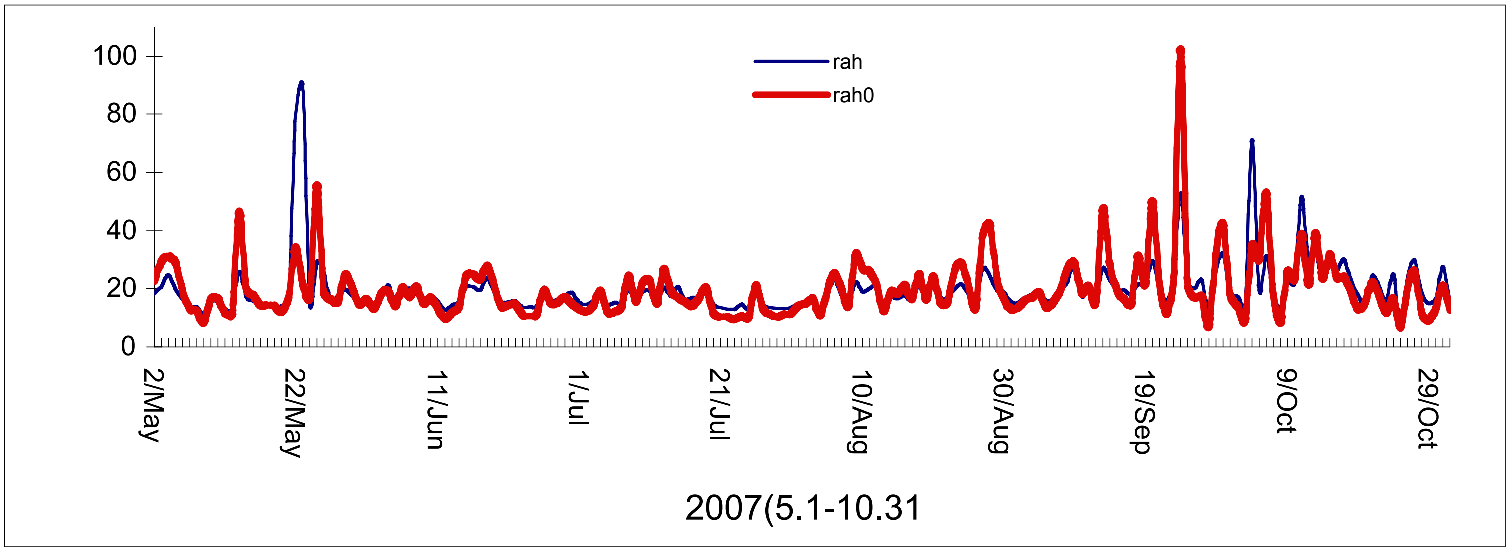
- **Is this method available under all the conditions?**

It is only available under neutral condition.

$\Phi_M = \Phi_E = 1$ and $z_{0,E} = z_{0,M}$, these two methods are the same

Aerodynamic Resistance Results

- The estimate of aerodynamic resistance



- Period from 9:00 a.m. to 5:30 p.m.
- Mean valuMean value of r_{ah} is 20.52 s m^{-1}
- e of r_{ah0} is 19.83 s m^{-1}

Note: r_c values average 270 s m^{-1}

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Potential Evapotranspiration

- **What is potential evapotranspiration (PET)?**

  PET expresses as the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand.

- **How can we estimate PET?**

  Lysimeters

  Eddy correlation

  Theoretical or empirical equation

  Multiplying standard pan evaporation data by a coefficient

- **Which method do we use in this study?**

  Penman-Monteith Equation

Potential Evapotranspiration

- **What is the Penman-Monteith Method?**

$$e_a^* = 0.611 \cdot \exp\left(\frac{17.3 \cdot T}{T + 237.3}\right)$$

$$PET = \frac{\Delta \cdot (K + L) + \rho_a \cdot c_a \cdot C_{at} \cdot e_a^* \cdot (1 - W_a)}{\rho_w \cdot \lambda_v \cdot \left[\Delta + \gamma \cdot (1 + C_{at} / C_{can})\right]}$$

$$\Delta = \frac{2508.3}{(T + 237.3)^2} \cdot \exp\left(\frac{17.3 \cdot T}{T + 237.3}\right)$$

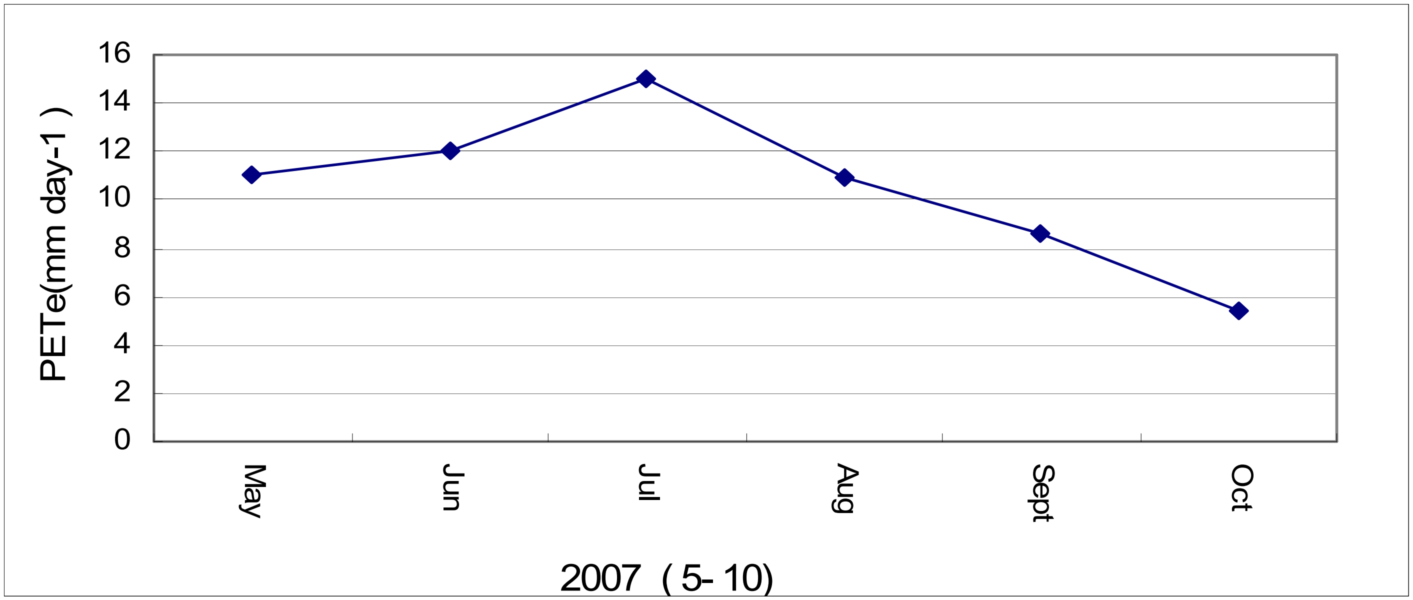
$$\lambda_v = 2.50 - 2.36 \times 10^{-3} \cdot T$$

$$\gamma \equiv \frac{c_a \cdot P}{0.622 \cdot \lambda_v}$$

$$C_{can} = f_s \cdot LAI \cdot C_{leaf}$$

PET Results

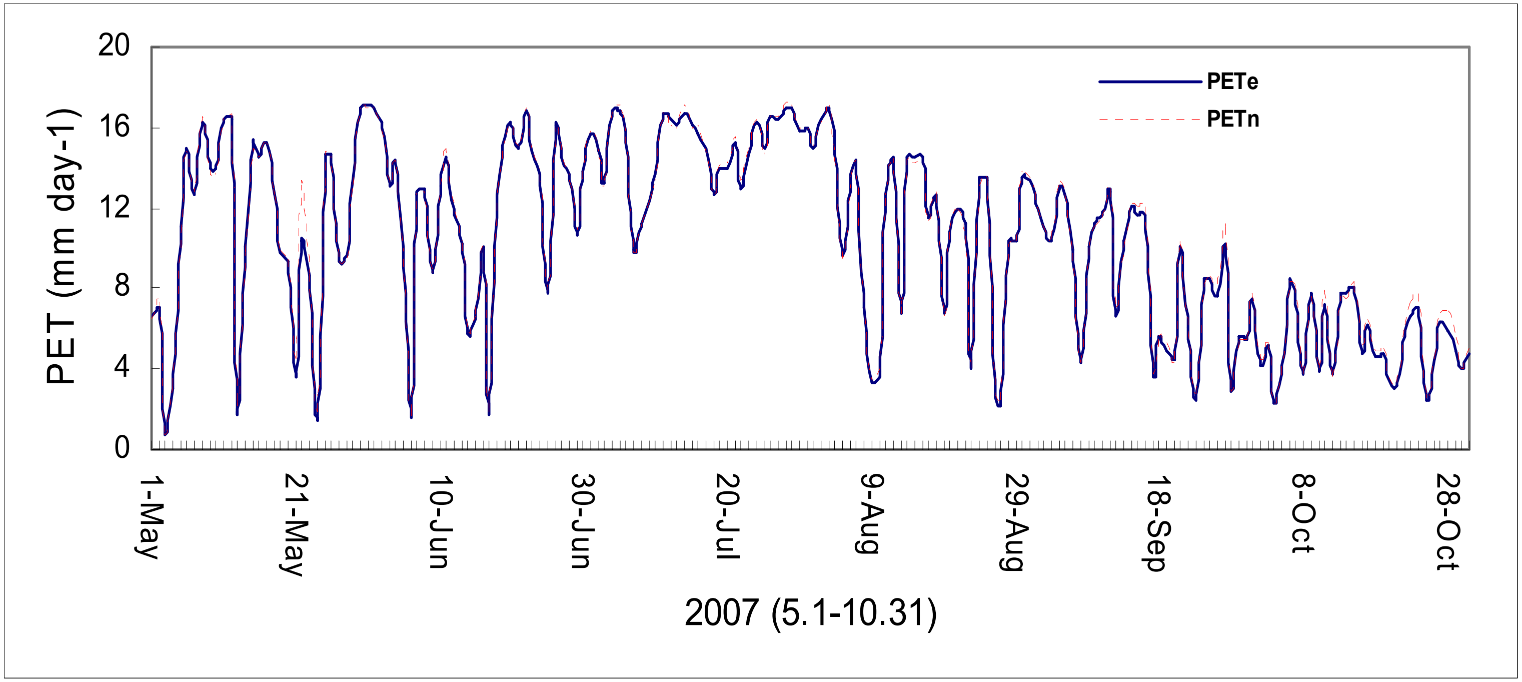
- PET seasonal trends in 2007



- Mean value is 10.52 mm day^{-1}
- Highest in July, lowest in October

PET Results (cont'd)

- Aerodynamic resistance effect on PET



- Sign test shows that PETe and PETn is not significant different
- PET is insensitive to aerodynamic resistance
- Mean value of r_{ah} is 20.52 s m^{-1} , the mean value of r_c is 267s m^{-1}

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TOPMODEL

- **What is TOPMODEL?**

  A physically-based model based on the concept of variable source area

- **Why we used TOPMODEL in this study?**

  It can be used to predict streamflow, overland and subsurface flow, and soil moisture deficit with less parameters

- **What is the objective for this study?**

  To simulate runoff in the Marmot Creek catchment using TOPMODEL

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TOPMODEL (cont'd)

- **How does TOPMODEL determine streamflow?**

$$q_{streamflow} = \frac{\sum_A a_i p + \sum_A a_i \left| s_i \right|}{A} + T_0 e^{-\lambda} e^{-\frac{\bar{s}}{m}}$$

where a_i is specific area, p is precipitation, s_i is local soil moisture deficit, A is watershed area, T_0 is saturated transmissivity, λ is the mean ln(a/tanβ) for the catchment, $\bar{s}$ is catchment-average saturation deficit, and m is parameter

- **How does TOPMODEL determine soil moisture deficit (s_i)?**

$$s_i = \bar{s} + m[\lambda - \ln(\frac{a}{\tan\beta})_x]$$

TOPMODEL (cont'd)

- **How many parameters involved in TOPMODEL?**

Parameter	Name in theory	Description	Range
SZM[m]	m	Transmissivity decay parameter	0.005-0.06
T0 [m^2h^{-1}]	$\ln(T_0)$	Effective lateral saturated transmissivity	0.1-8
TD [$m\ h^{-1}$]	t_d	Unsaturated zone time delay	0.1-500
CHV [$m\ h^{-1}$]	CHV	Channel velocity	100-10000
RV [$m^{-2}\ h^{-1}$]	RV	Routing velocity	100-10000
SRMAX [m]	SRmax	Maximum allowable root zone storage	0.005-0.3
SR0[m]	SR0	Initial root zone deficit	0.0-0.3

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TOPMODEL (cont'd)

- **How to calibrate the parameters?**

  Genetic Algorithm

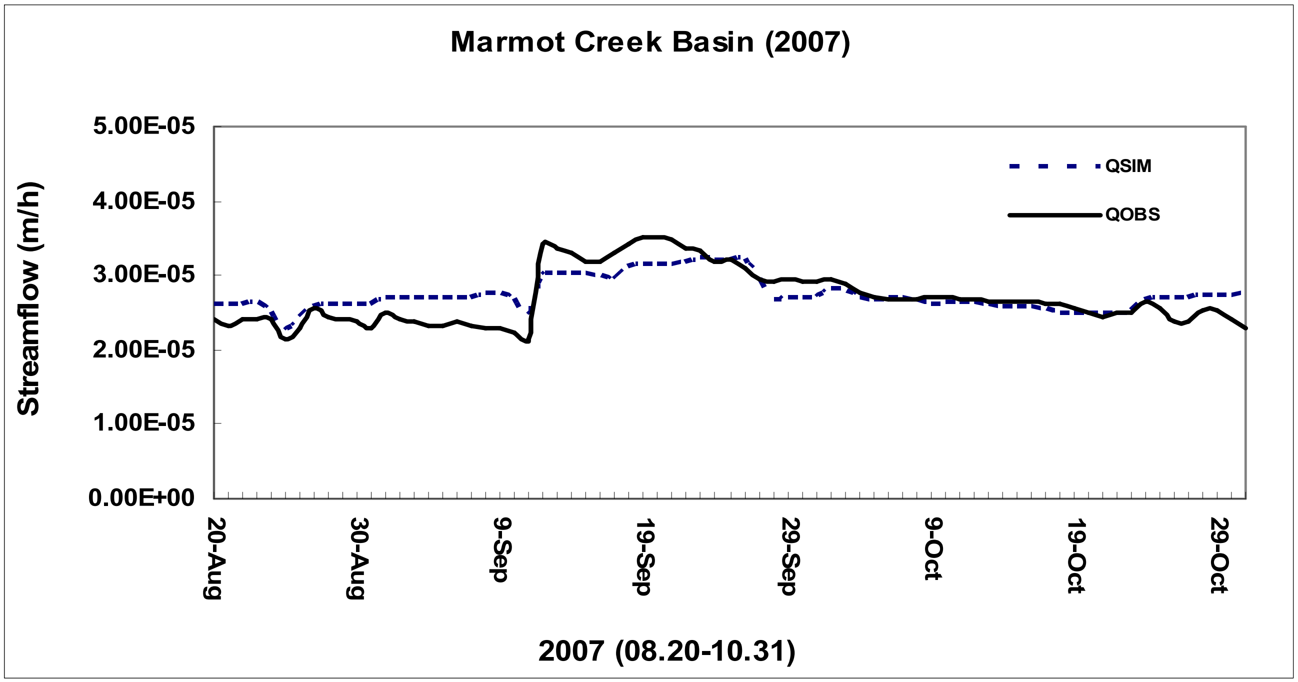
- **How to evaluate the model efficiency?**

$$EFF = \frac{\sum(QOBS_i - QOBS_m)^2 - \sum(QOBS_i - QSIM_i)^2}{\sum(QOBS_i - QOBS_m)^2}$$

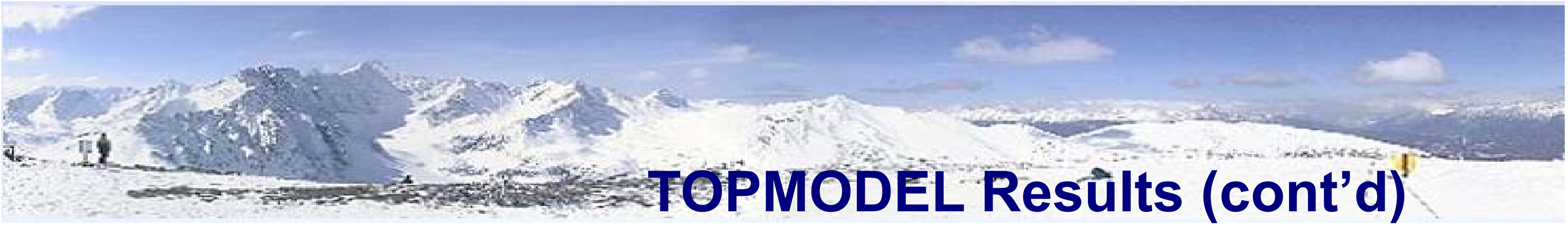
Where $QOBS_i$ is the observed streamflow, $QSIM_i$ is the simulated streamflow, and QOBSm is the mean of the observed streamflow.

TOPMODEL Results

- The result of calibration



- Period of 20th August to 31st October in 2007
- The model efficiency value is 0.611



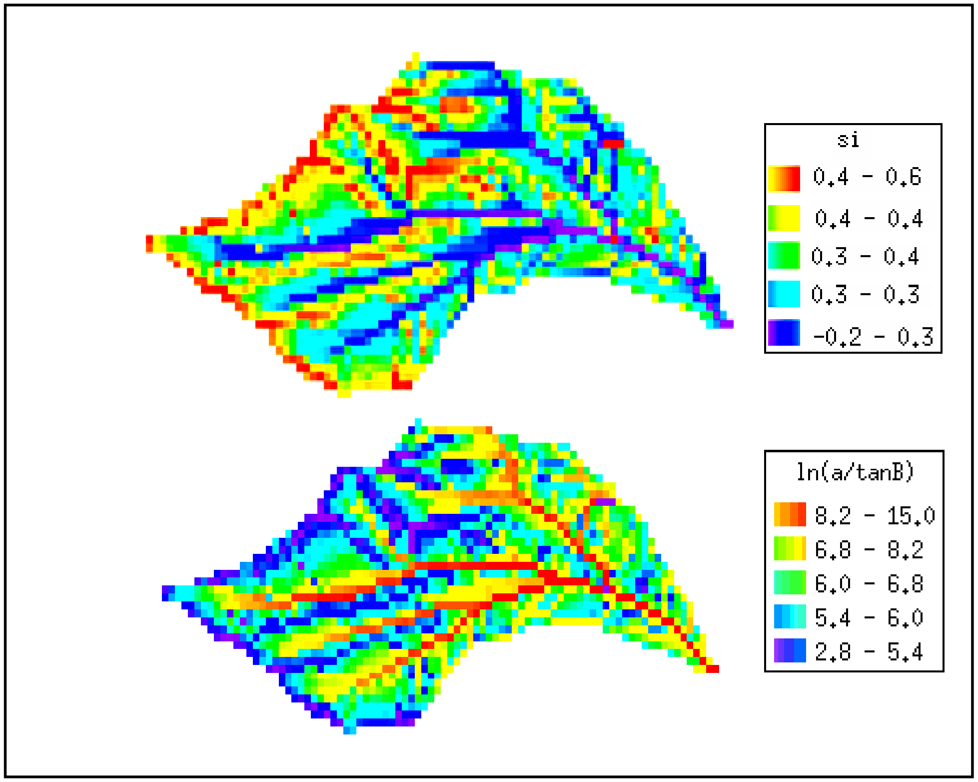
TOPMODEL Results (cont'd)

- **Calibration results for 1-meter and 90-meter resolution DEM, using D8 and D∞.**

	Flow	SZM (m)	T0 (m^2h^{-1})	SR0 (m)	SRMAX (m)	CHV $(m\ h^{-1})$	RV $(m^{-2}h^{-1})$	Td (mh^{-1})	EFF	QSUB (%)
1	**D8**	0.046	0.29	0.0015	0.0059	371.53	449.81	382.24	0.611	84.91
	D∞	0.046	0.29	0.0015	0.0059	371.53	449.81	382.24	0.583	86.4
90	**D8**	0.060	1.18	0.00006	0.0060	1725.00	114.84	261.85	0.656	52.55
	D∞	0.060	1.18	0.00006	0.0060	1725.00	114.84	261.85	0.565	53.96

TOPMODEL Results (cont'd)

- The relation between soil moisture deficit(si) and topographic index [ln(a/tanβ)] on August 28th in 2007.
- Large value of ln(a/tanβ) indicates the locations within a watershed most likely to be saturated and produce overland flow



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Land Cover Classes Vs Topographic Index

- **What are the procedures of land cover classification?**

  Images processing

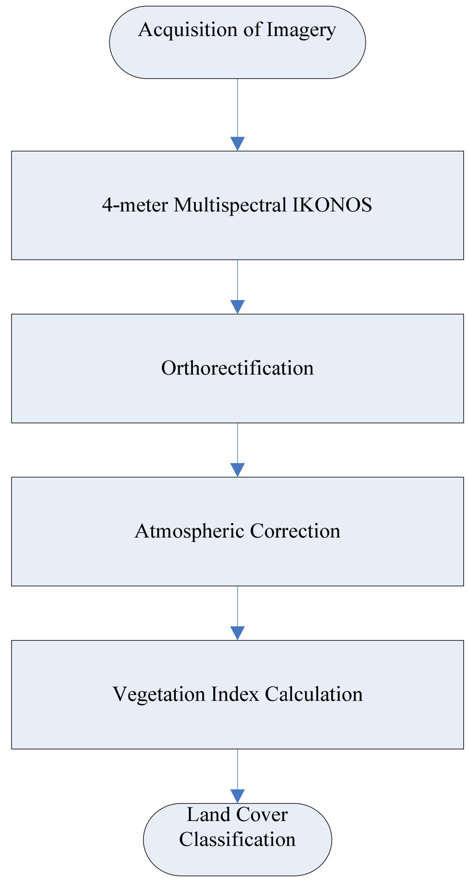
  Calculation of vegetation index

  Land cover classification

- **Which Normalized Difference Vegetation Index (NDVI) is used in this study?**

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \qquad -1.0 \le NDVI \le 1.0$$

Where ρ_{nir} and ρ_{red} represent reflectance at the red and near-infrared (NIR) wavelengths, respectively.

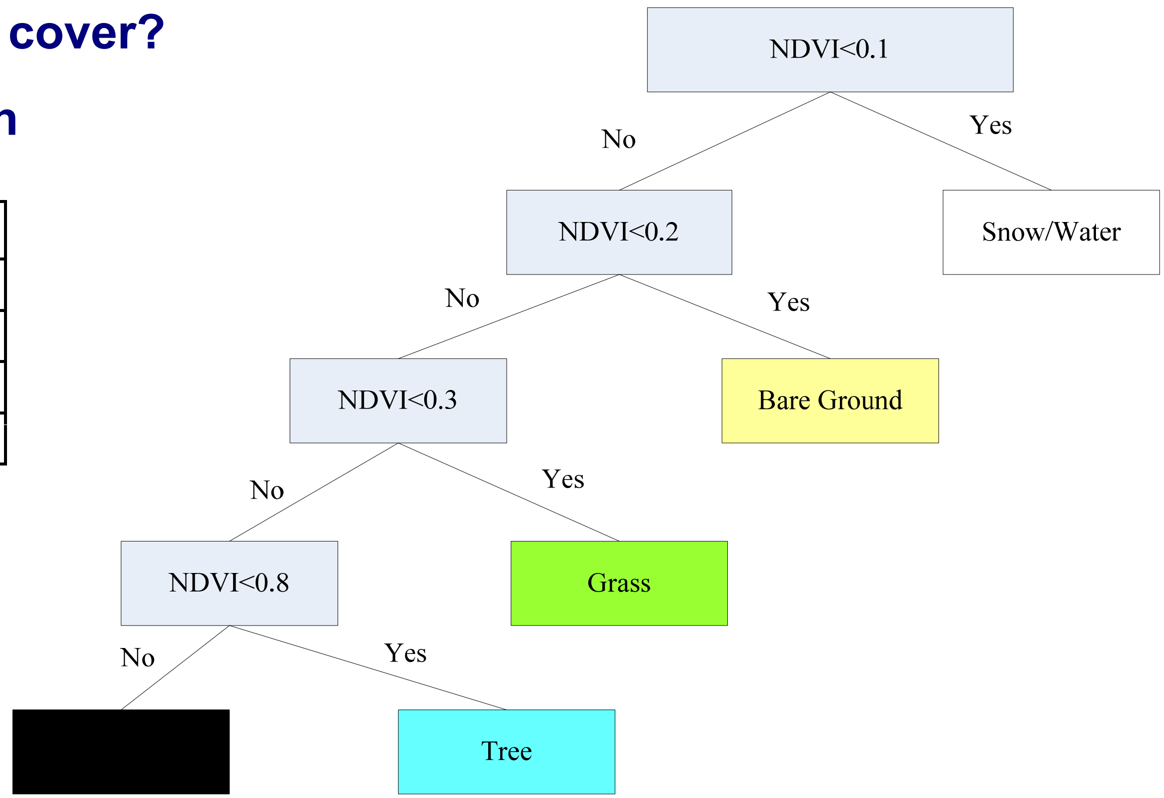


Land Cover Classes Vs Topographic Index

- **How can we classify the land cover?**

  Using Decision tree approach

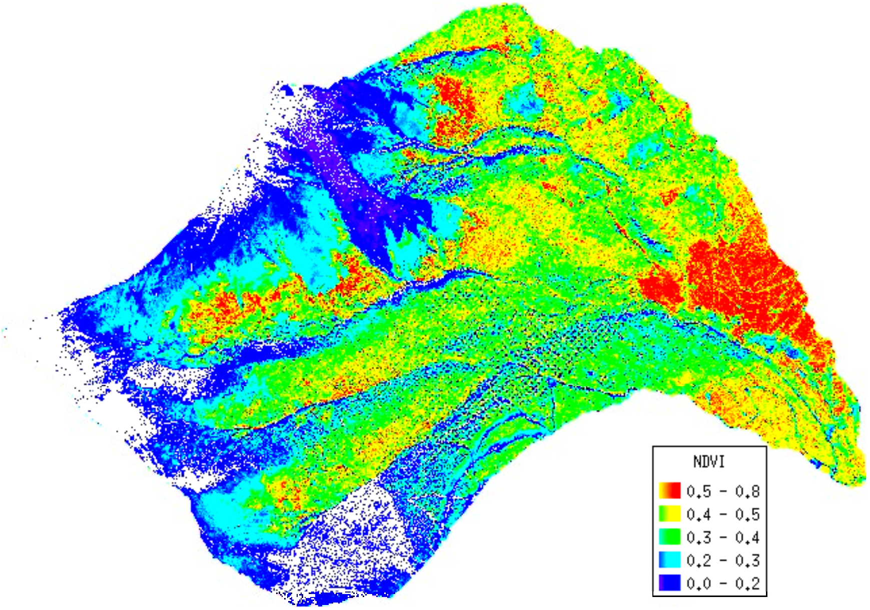
Land Cover Classes	NDVI Rang
Snow or Water	NDVI<0.1
Bare Ground	0.1≤ NDVI < 0.2
Grass	0.2≤ NDVI<0.3
Tree	0.3≤ NDVI <0.8

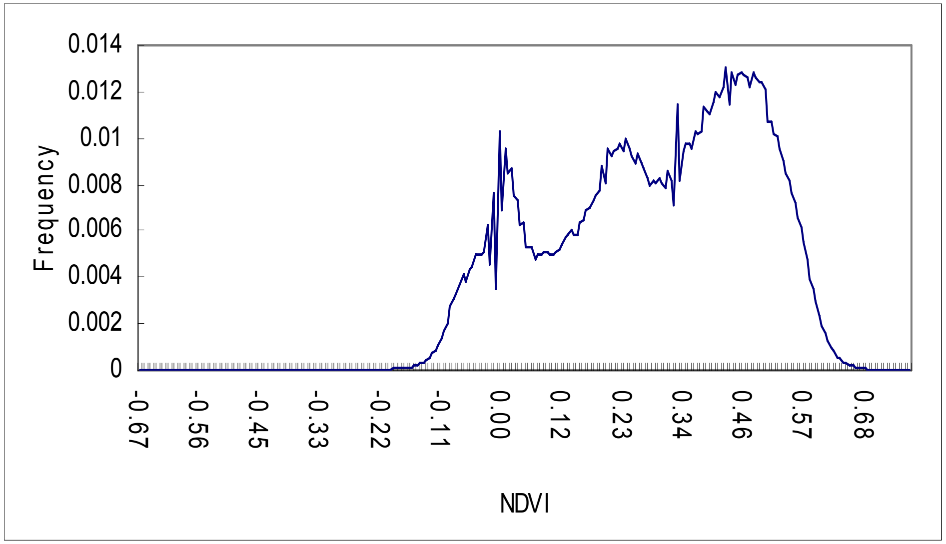


NDVI Calculation Results

- **The results of NDVI calculation**

  NDVI in this study area varies from -0.67 to 0.77, mean value is 0.29, in October 18th, 2003.





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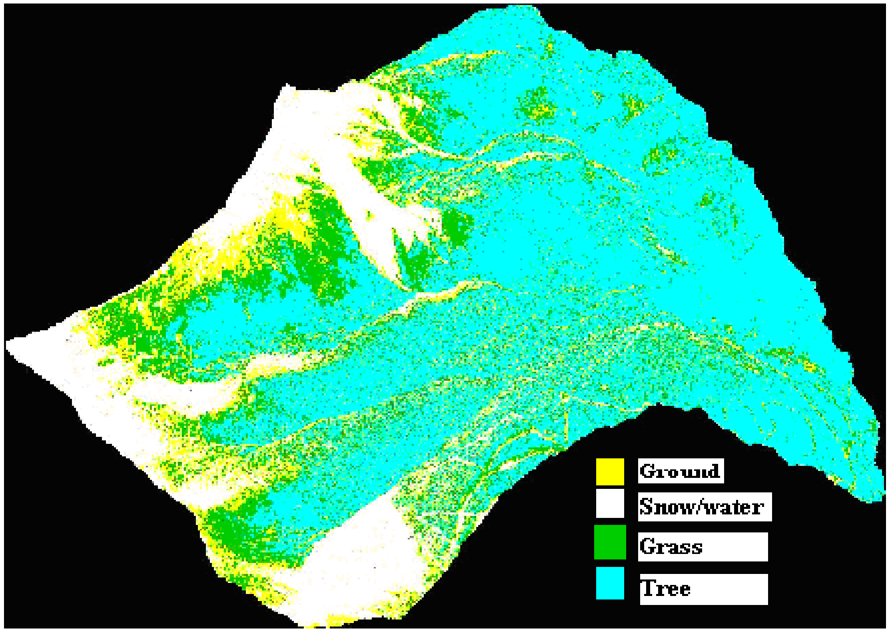
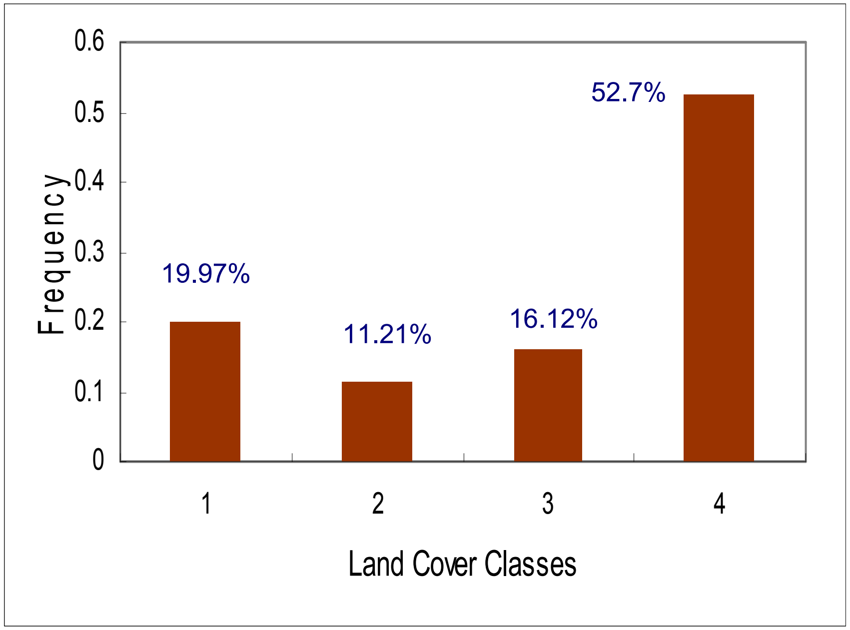
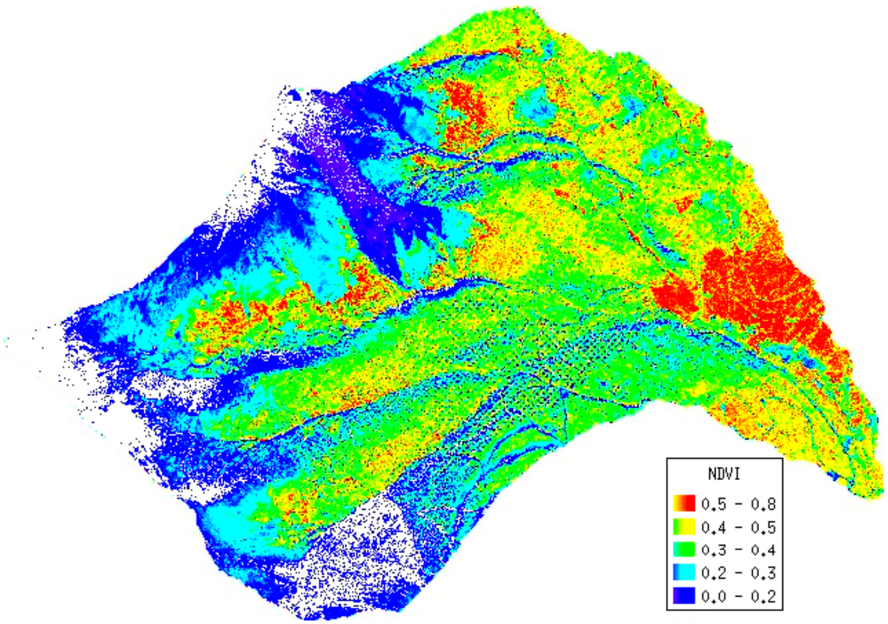
Land Cover Classification Results

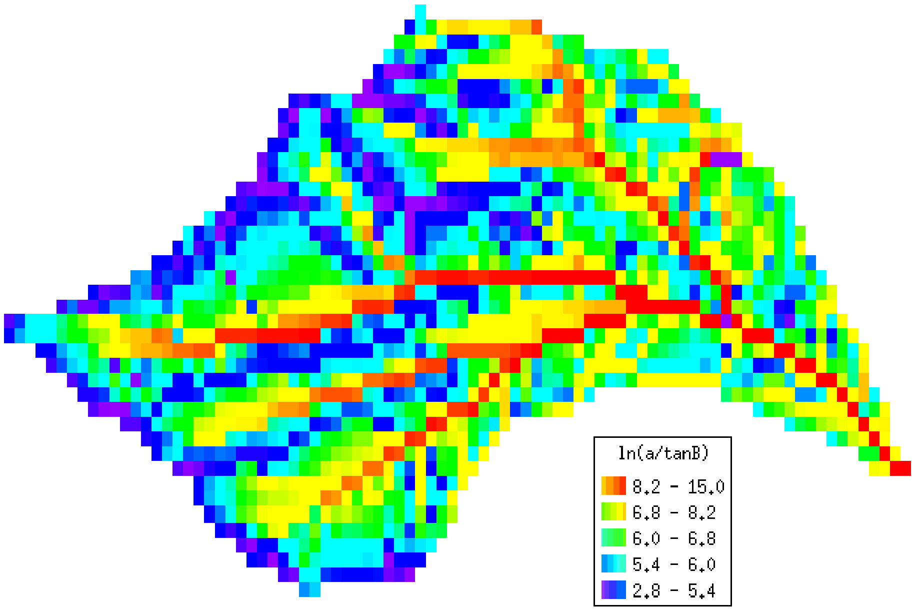
- **The results of land cover classification**





Developing New Measures of Similarity





NDVI - Land Cover

Topographic Index - Terrain

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Future work

Future Work

- **Theme II - Parameterization**

Potential evapotranspiration estimates

Topographic Index Calculation - scaling behavior

Develop Similarity Estimates - terrain, topo, elevation, aspect

- **Theme III - Prediction**

Implement TOPMODEL redistribution within CLASS

Prediction of finer scale topography

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