Hydromythology and Prediction using Available Information

John Pomeroy, Xing Fang, Kevin Shook, Cherie Westbrook, Tom Brown, Matt MacDonald, Chris DeBeer, Chad Ellis and Edgar Herrera

Centre for Hydrology, Univ Saskatchewan, Saskatoon, Canada

www.usask.ca/hydrology

How to Predict in Data Poor Basins?

- Lack of streamflow data means that model calibration opportunities are restricted.
- Typically there is also a lack of detailed meteorological data.
  - Reanalysis data
  - NWP model outputs
  - Extrapolation
- Satellite information can provide good surface vegetation cover information.
- DEMs are becoming excellent.
- Many regions have adequate soil information.
- Groundwater information is often lacking.
- Climate and sometimes land use changes are occurring.
- Can we find the appropriate data and parameters for PUB in data poor regions?

Stop the Bullet or Dodge the Bullet?

Stop Hydromythology Now!

- Defn: *Older concepts that have been dismissed by scientific investigation but persist in hydrological models*.
- Examples:
  - Radiation is impossible to estimate with normal meteorological data
    - Evapotranspiration can be estimated by temperature and wind functions
    - Temperature index melt of snow and soil thaw
  - Snowfall determines snow available for melt
    - Sublimation = 0
    - Snowfall gauge correction = snow redistribution loss
  - Soils can be represented as uniform porous media and subjected to clever mathematical manipulations
    - Macropores = 0
    - Green-Ampt or Richard's Eq. can work "as is" or are still physically based when heavily calibrated from streamflow
  - All land surfaces drain freely to streams with quick flow at overland flow velocities
    - Hortonian overland flow
    - Contributing area = 100%
  - Frozen soils behave like unfrozen soils
    - Calibration of unfrozen soil infiltration for frozen conditions

Science or Mythology?

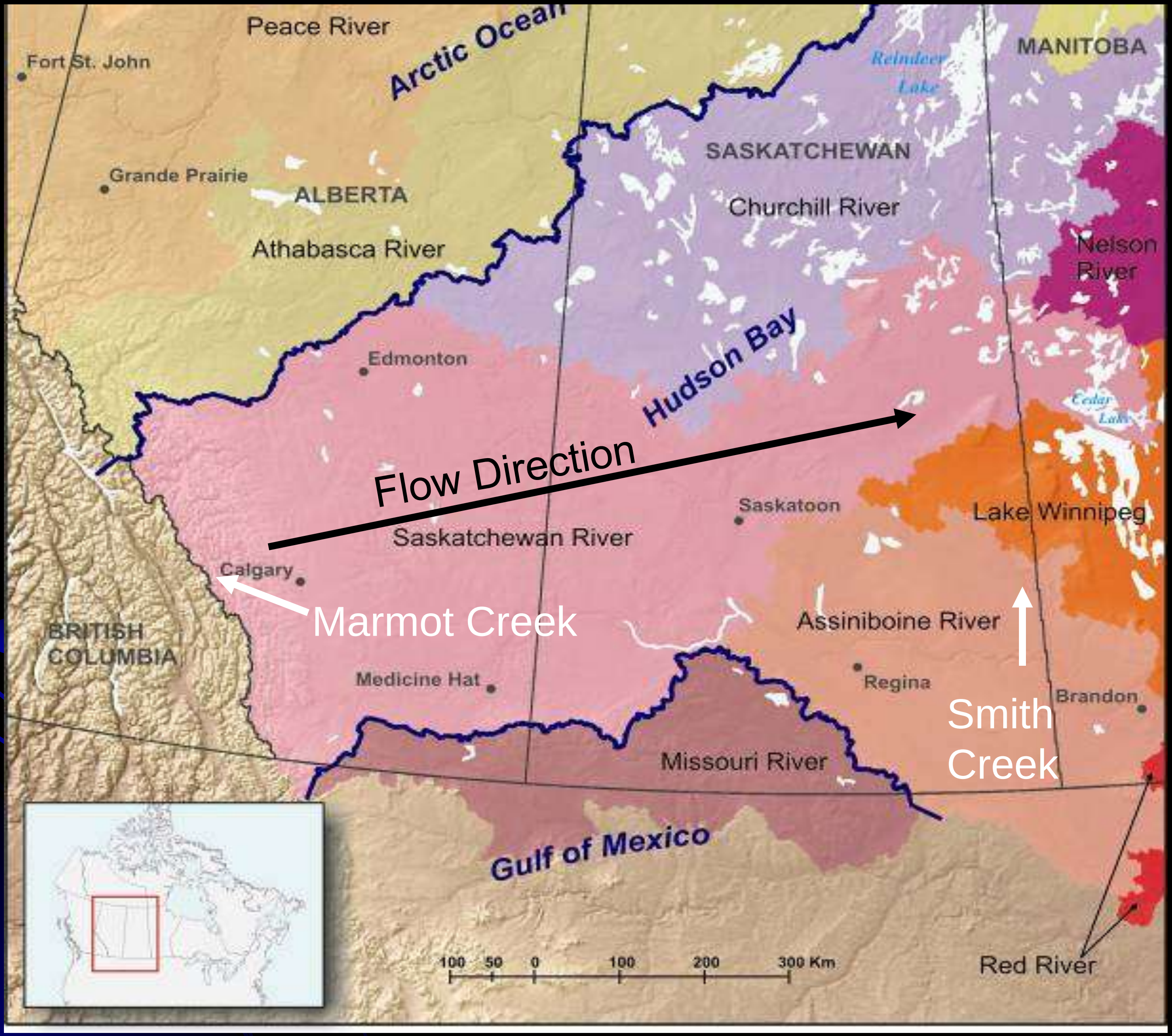
- Conceptual models sometimes accept mythology and “calibrate” to live with it.
- Models must reject mythology and incorporate scientific advances

Process-based Catchment Modelling

- Multi-scale modelling, selected field studies and remote sensing can be used for finding appropriate model structure and parameters.
- Appropriate parameterisations help diminish "hydromythodologies".
- Modelling using our understanding of hydrological processes is both scientifically satisfying and a robust approach to dealing with non-stationary systems.

- Failures of uncalibrated modelling at research basins are instructive. Embrace our failures.
  - What are the limits to prediction of the physically based approach?
  - How can conceptual and physically based approaches be used in process based catchment modelling?

Research Basins



Cold Regions Hydrological Model Platform: CRHM

- Modular, object oriented – purpose built from C++ modules
- Modules based upon +45 years of hydrology research at Univ of Saskatchewan and Environment Canada
- Range of complexity and physical basis available in modules
- Structure set by user depending on objective function
- Parameters set by knowledge rather than optimization
- Hydrological Response Unit (HRU) basis
  - landscape unit with characteristic hydrological processes/response
  - single parameter set
  - horizontal interaction along flow cascade matrix
  - Model tracks state variables and flows for HRU
- Coupled energy and mass balance, process algorithms applied to HRUs via module selection
- HRU connected aerodynamically for blowing snow and via dynamic drainage networks for streamflow
- Flexible - can be configured for prairie, mountain, boreal, arctic basins
- Sub-basins connected via Muskingum routing

Pomeroy et al., 2007 *Hydrol. Proc.*

Tom Brown, CRHM Modeller

Rationale for CRHM Platform

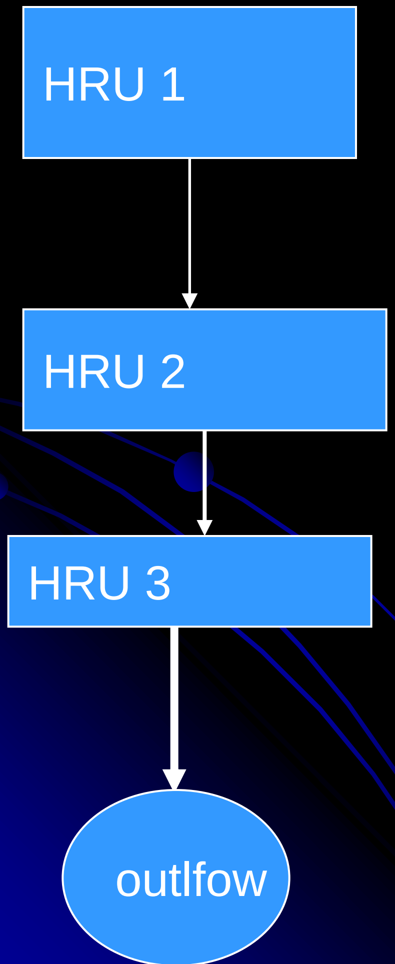
- Frustration with adding locally important process algorithms to existing hydrological models
- Frustration with trying to fit inappropriate structure of existing models to basins
- Frustration with inability to fit conceptual spatial representations to reality.
- Frustration with models that only focus on streamflow response to precipitation
- Frustration with attempts to teach modelling to hydrologists using antiquated computer languages, difficult user interface, limited documentation of models
- Frustration with the lack of a graphical system to evaluate model inputs and outputs

Hydrological Response Units

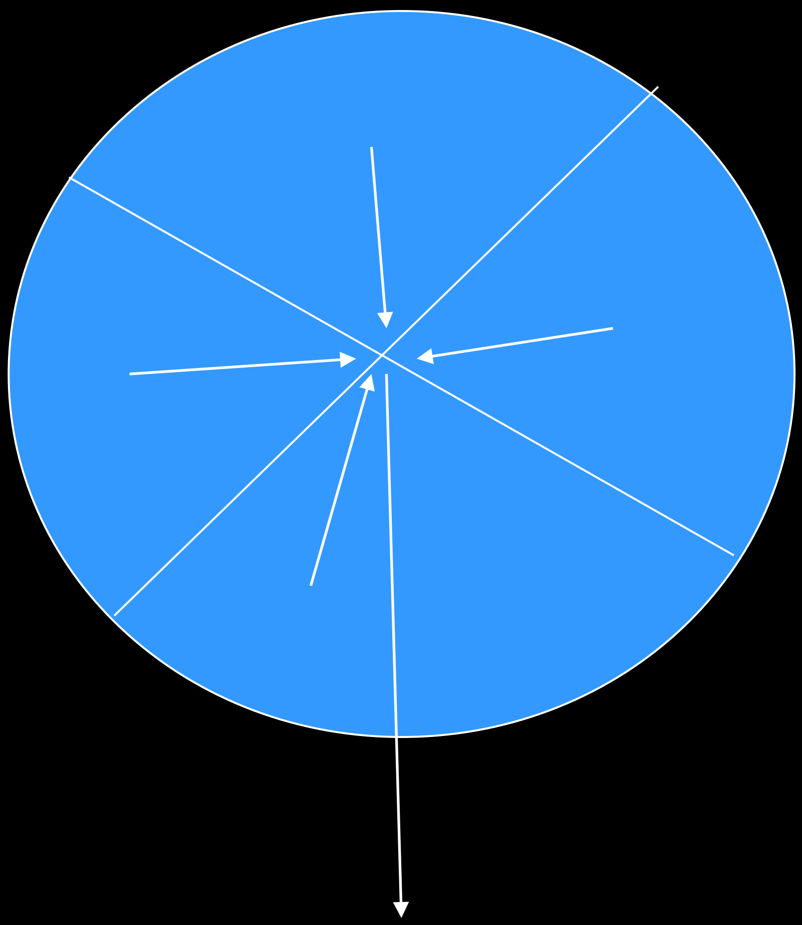
- A HRU is a spatial unit in the basin that has 3 groups of attributes
  - biophysical structure - soils, vegetation, drainage, slope, elevation, area (determine from GIS, maps)
  - hydrological state – snow water equivalent, snow internal energy, intercepted snow load, soil moisture, depressional storage, lake storage, water table (track using model)
  - hydrological flux - snow transport, sublimation, evaporation, melt discharge, infiltration, drainage, runoff. Fluxes are determined using fluxes from adjacent HRU and so depend on location in a flow sequence.
- HRU need not be spatially continuous but must have some approximate geographical location (e.g. in a catena) or location in a hydrological flow sequence

Hydrological Response Units

Sequential HRU – landscape connectivity



HRU – draining directly to stream



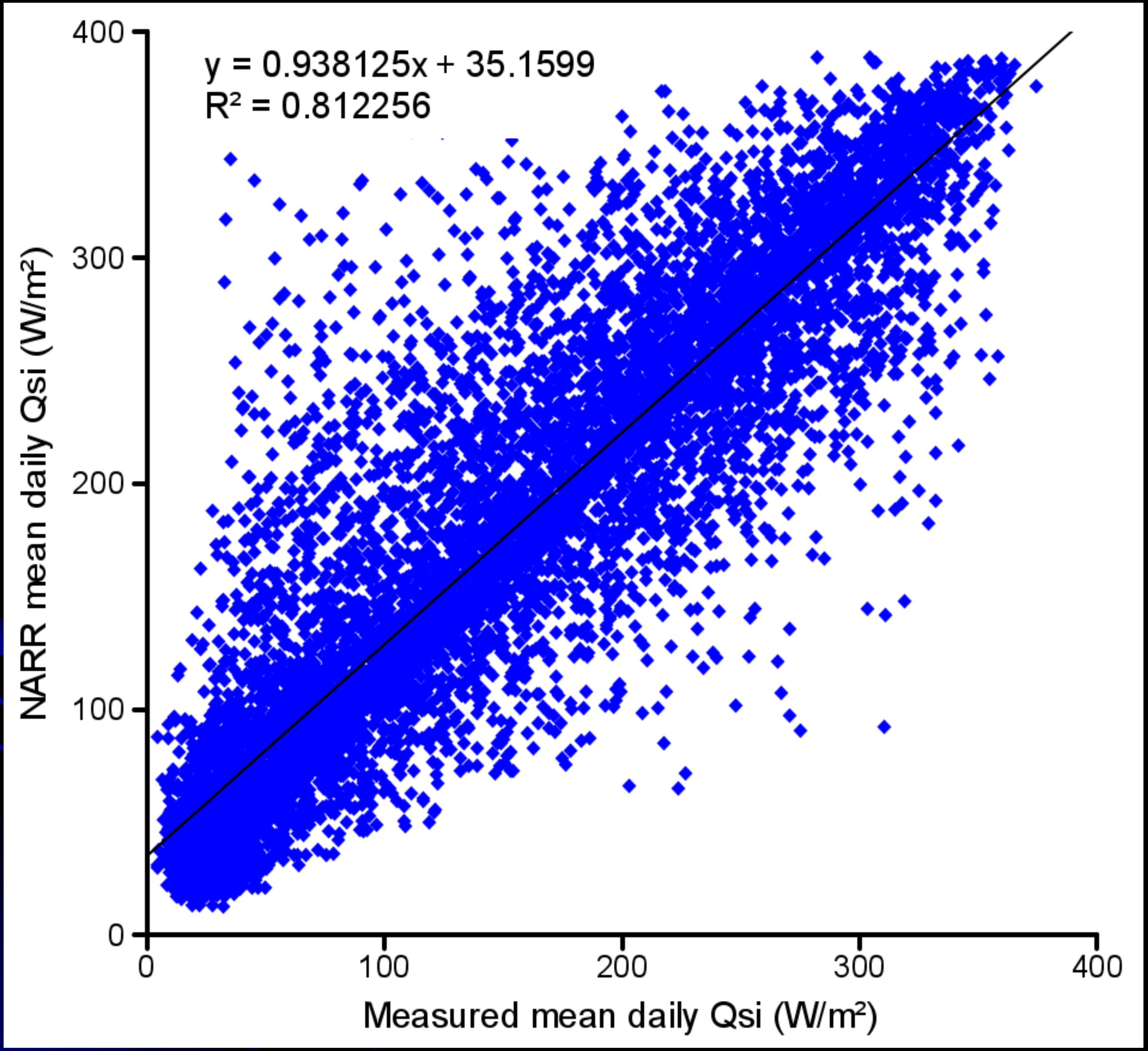
Estimating Radiation for Energy Balance

- Theoretical superiority of energy balance calculations are well known for calculating sublimation, snowmelt and evapotranspiration.
- Energy balance estimations are robust and appropriate for extreme events, climate and land use change studies.
- Use of energy-balance is restricted by difficulty in obtaining measured solar radiation data.

CRHM data requirements

- CRHM normally requires hourly or daily values of:
  - Air temperature, humidity, precipitation,
  - Wind speed, Solar radiation
- CRHM can estimate incoming longwave and net radiation from shortwave
- Solar radiation can be
  - measured,
  - estimated from NWP reanalysis data,
  - estimated from observed sunshine hours or
  - estimated from empirical techniques that rely on air temperature

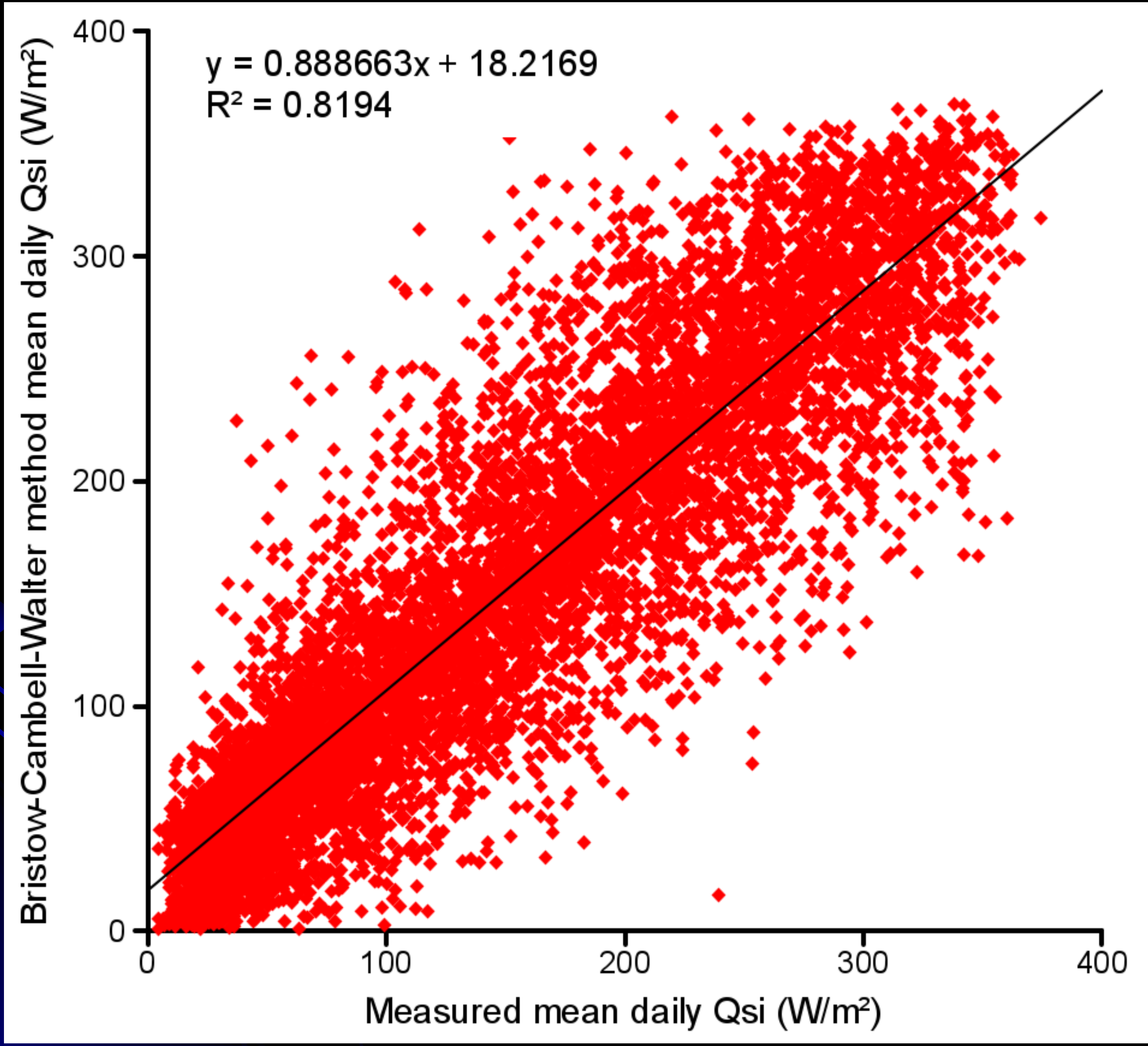
Edmonton 1979-2000



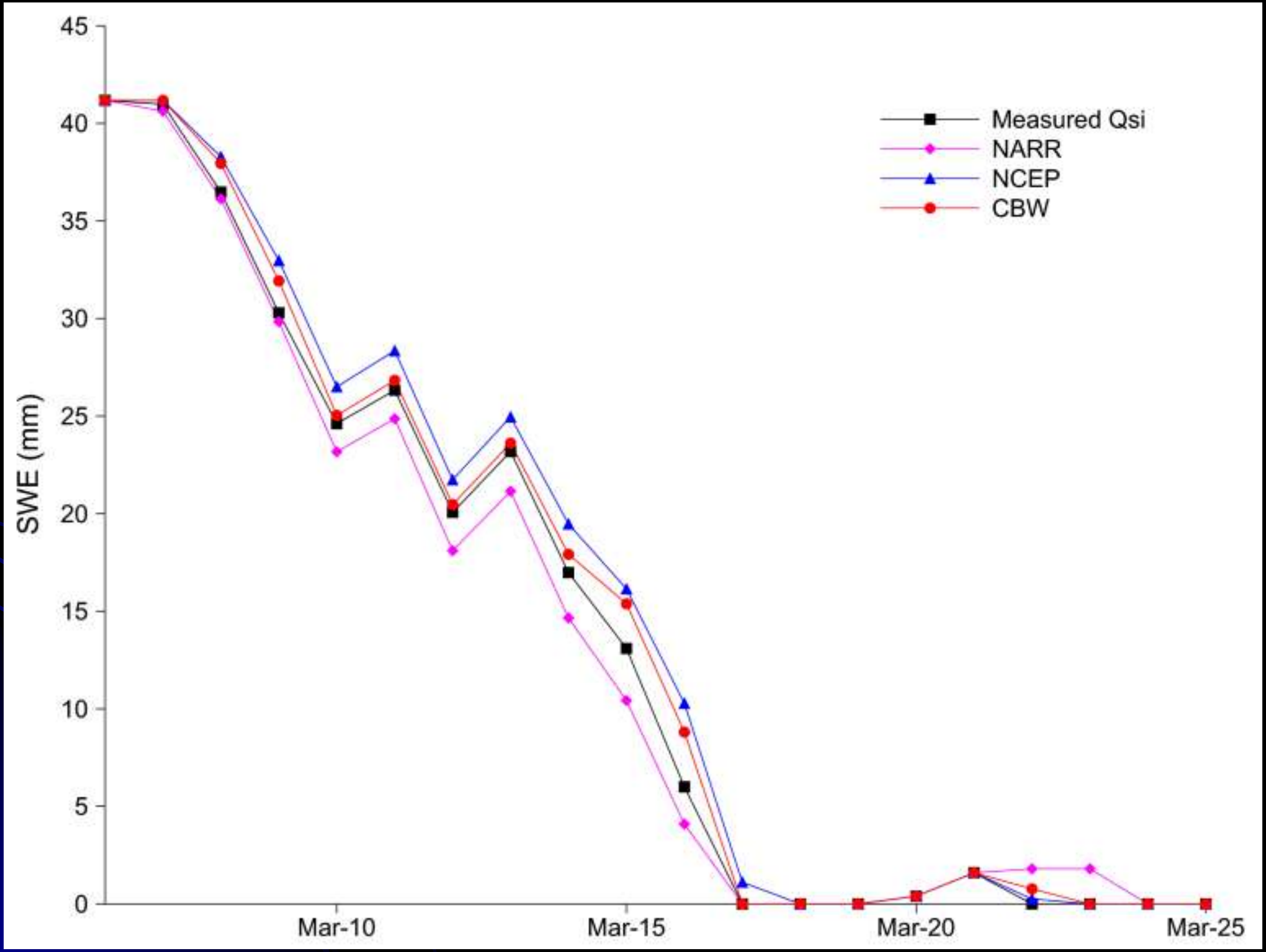
Empirical atmospheric transmittance equations

- Q_{si} can be calculated directly if the atmospheric transmittence is known
- Many similar relationships, all give similar results:
  - Bristow and Campbell and Walter et al.
  - Annandale
- All use a simple relationship between daily atmospheric transmittance and the range of daily air temperatures

Edmonton 1979-2000

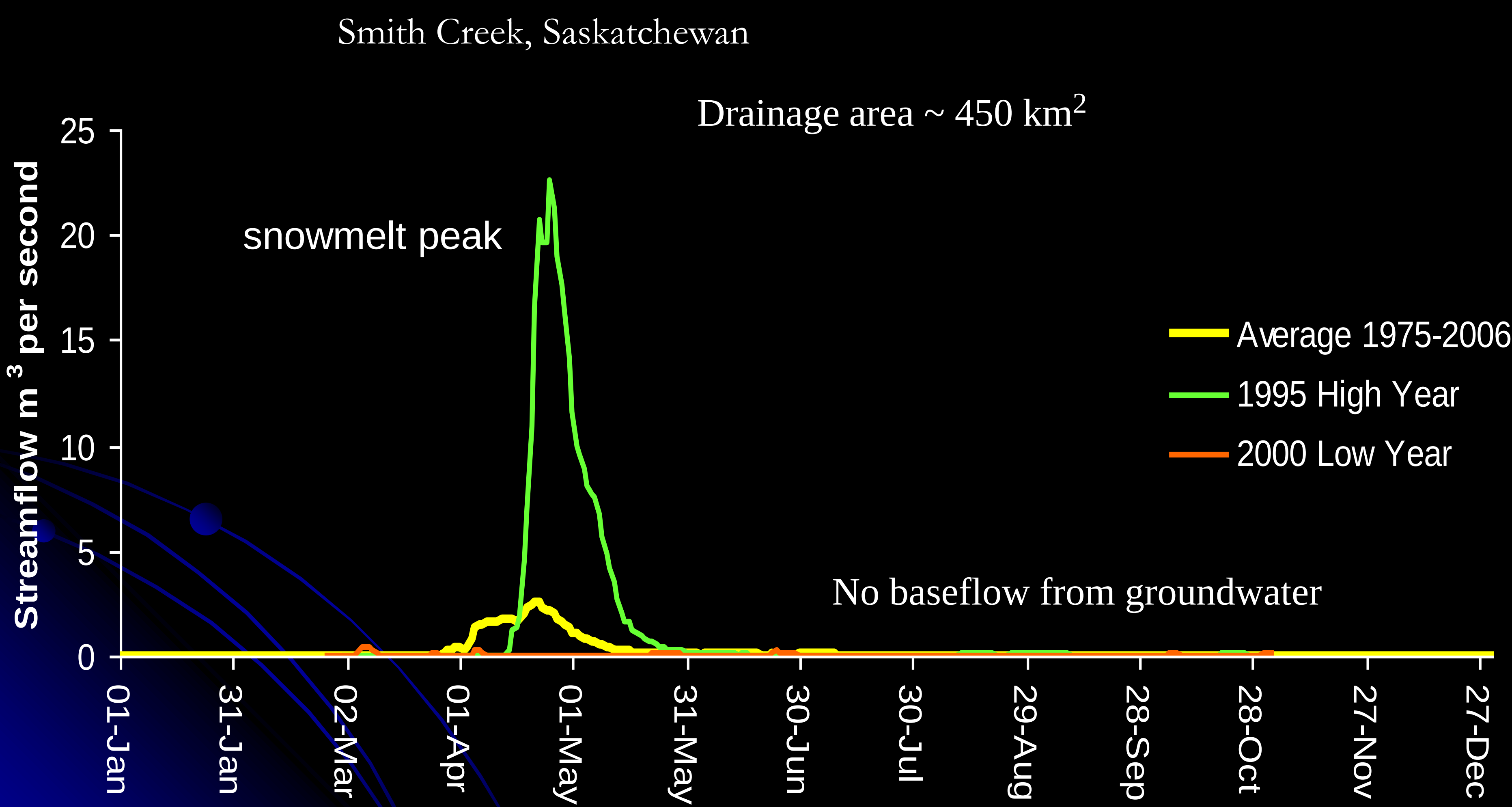


CRHM Snowmelt Simulation



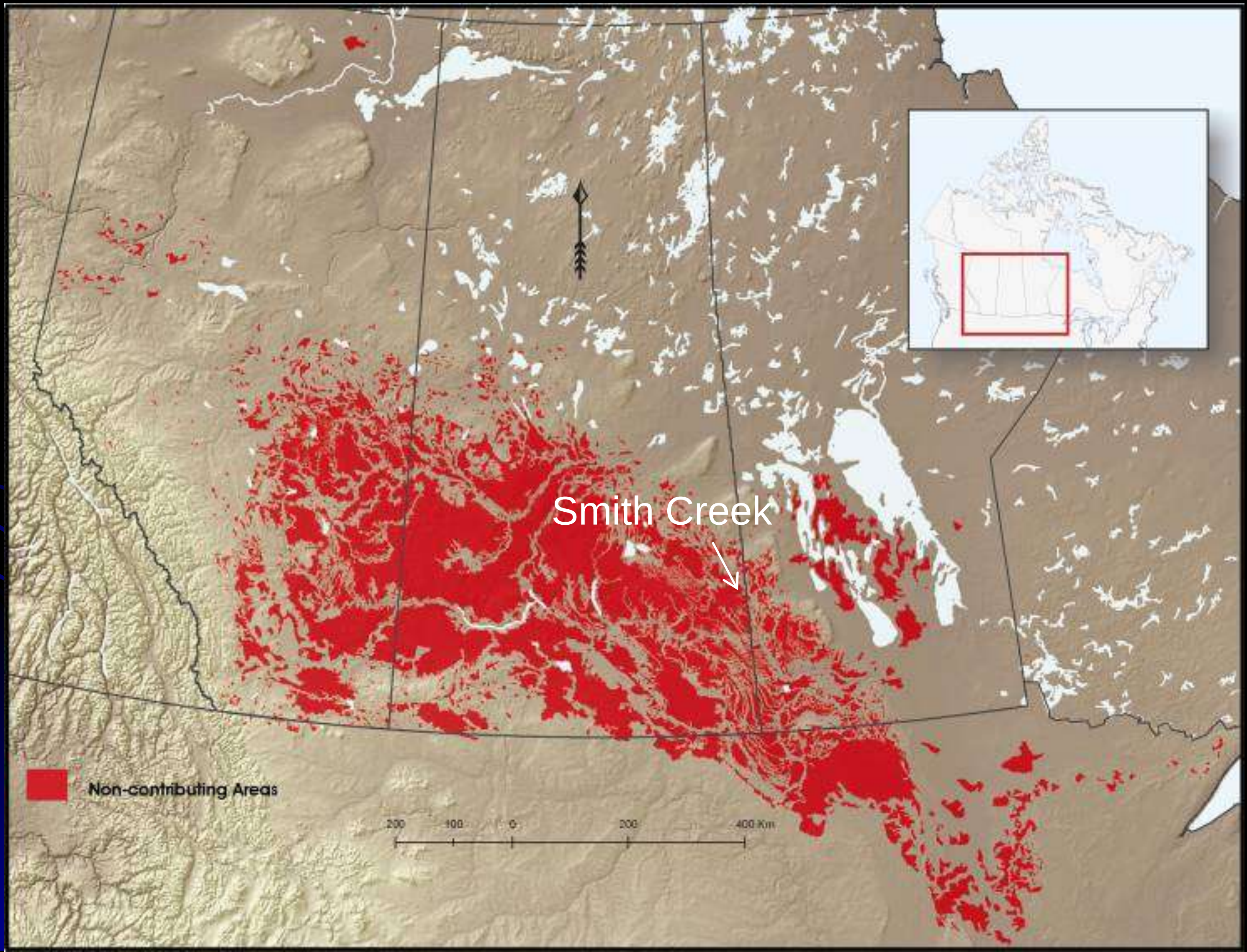
Canadian Prairie Runoff Generation

What does the Hydrograph Tell Us?



Variable Connectivity and Storage in Prairie Drainage Networks

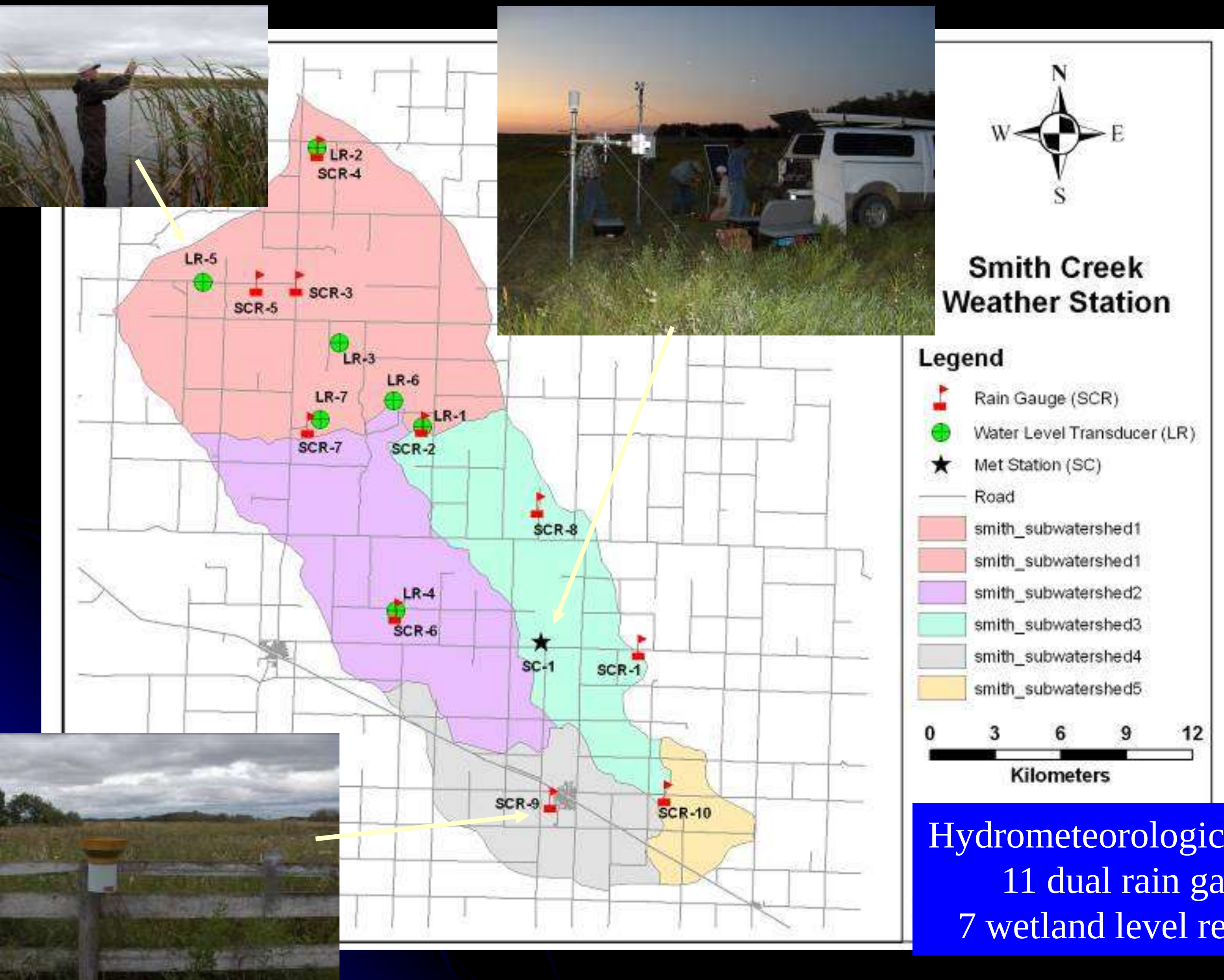
Non-Contributing Areas to Streamflow a Prairie Characteristic



Smith Creek Research Basin

- Established 2007 to study effects of wetland drainage on contributing area dynamics and streamflow generation

Instrumentation of Smith Creek

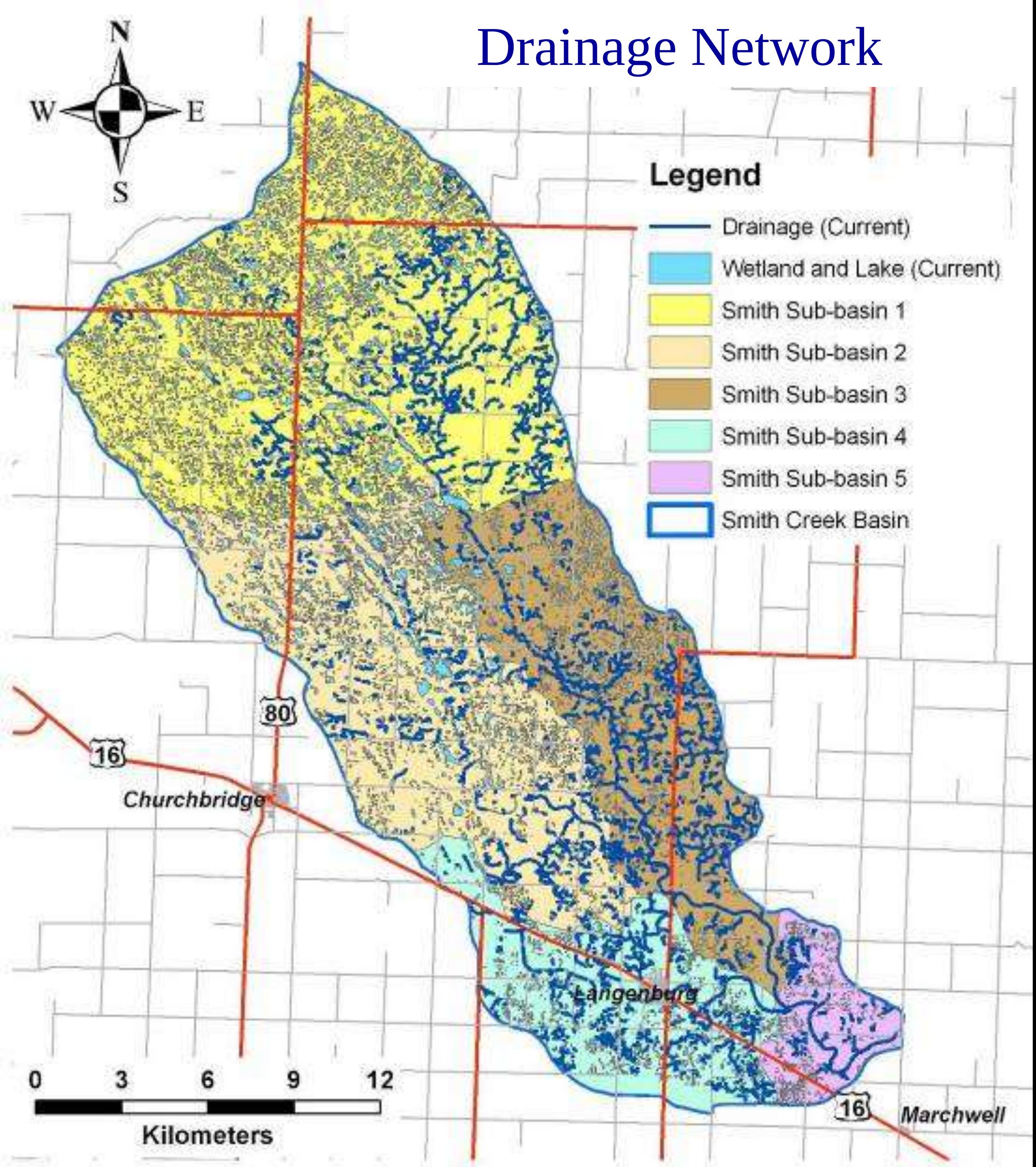


Completed Summer 2007

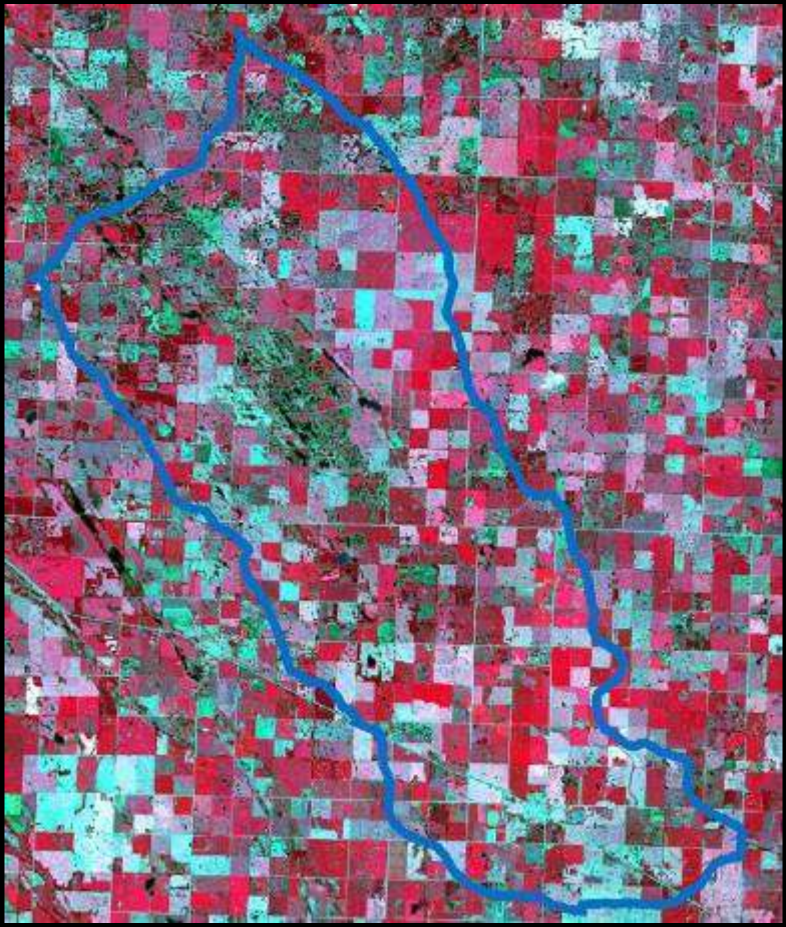
Hydrometeorological Station
11 dual rain gauges
7 wetland level recorders

Snow, Soil and Wetland Surveys

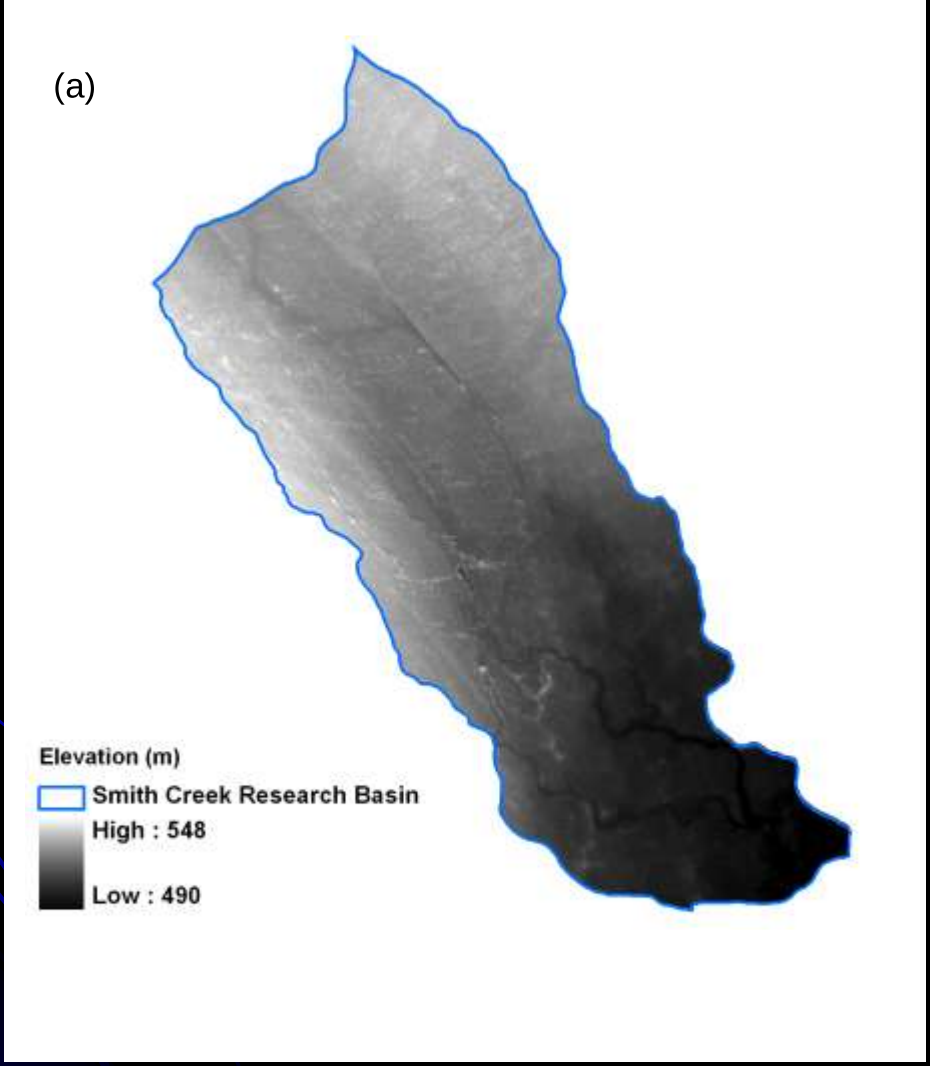
Smith Creek Basin Characteristics



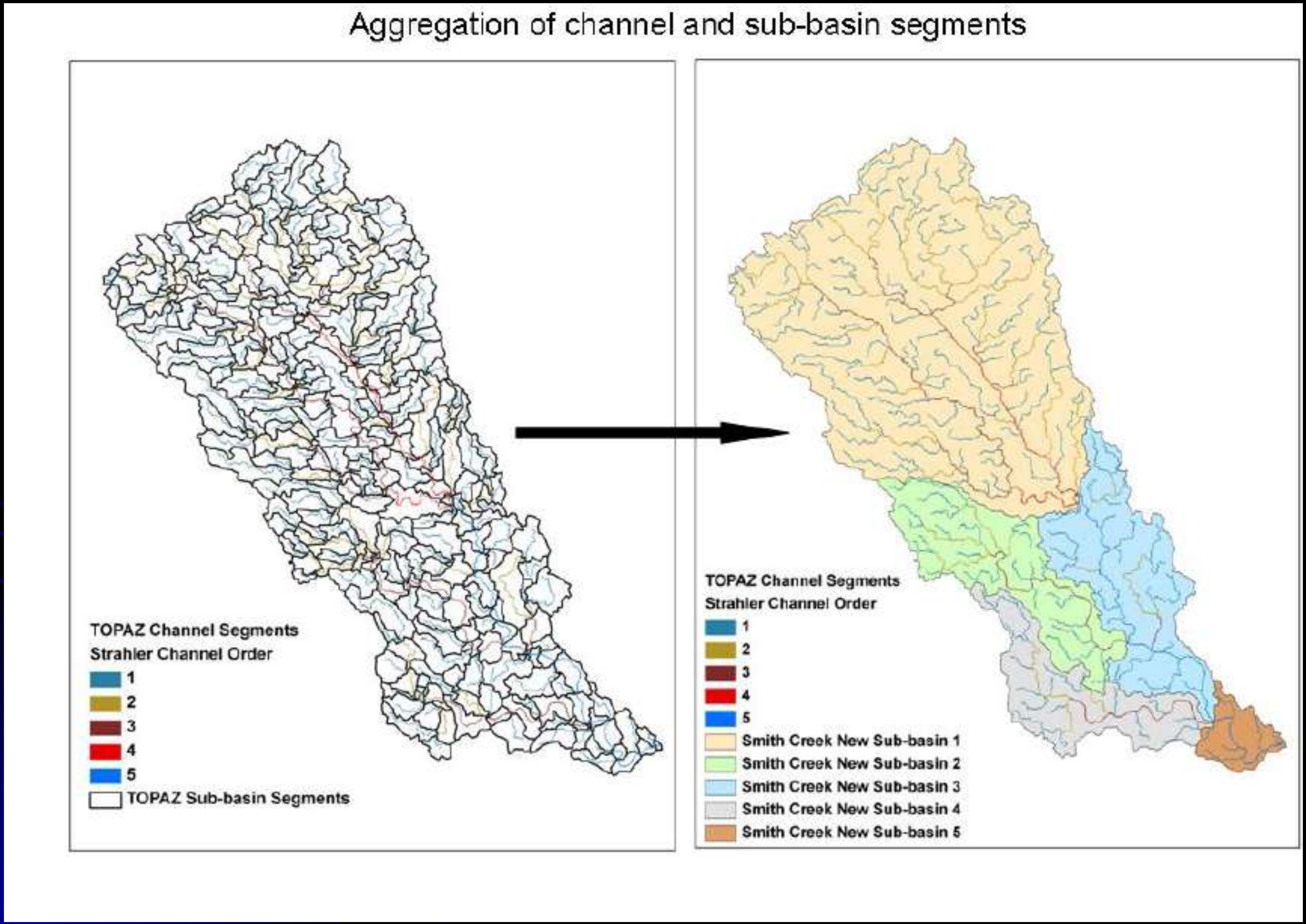
Spot Satellite Image



LiDAR – Light Detection and Ranging – for high resolution topography



LiDAR-Derived Drainage Network



Derivation of Wetland Depressions

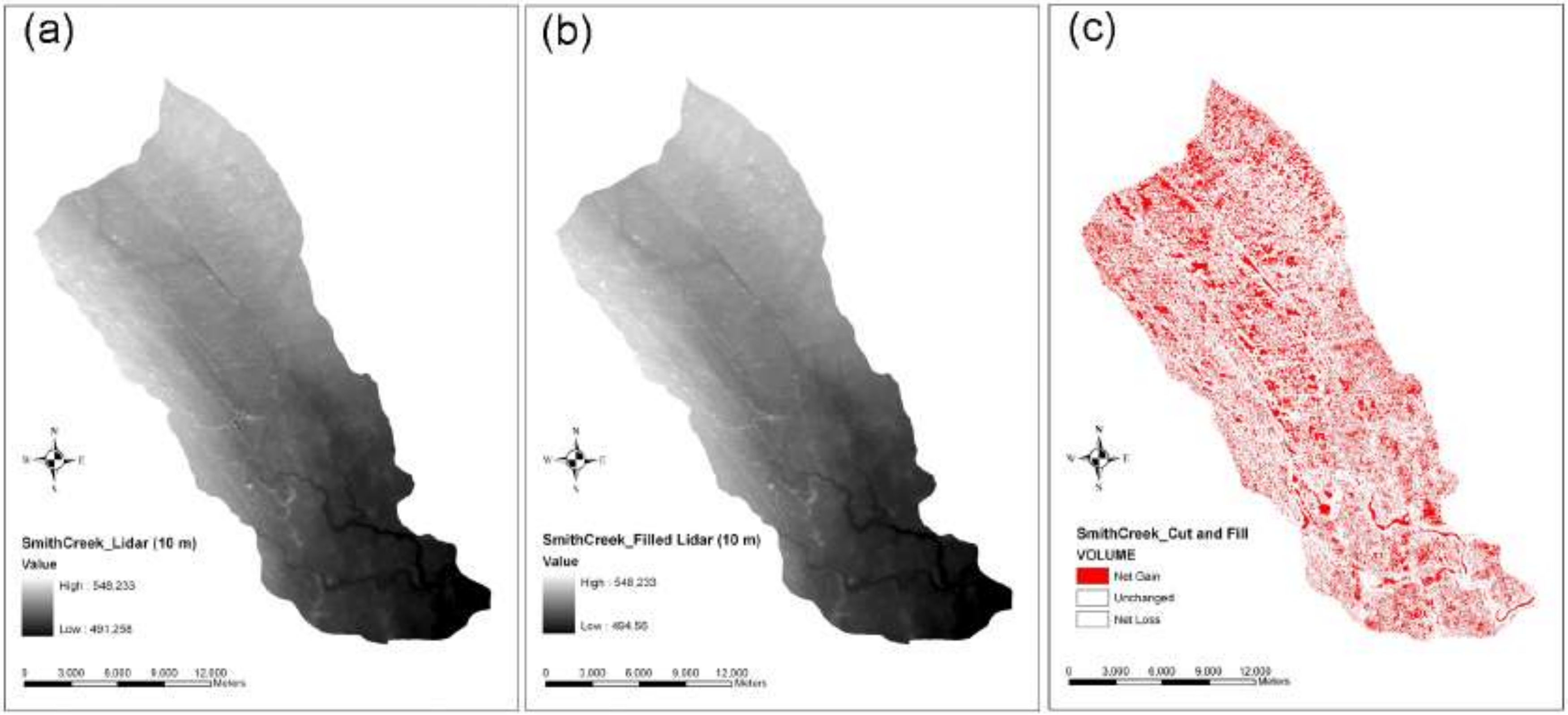
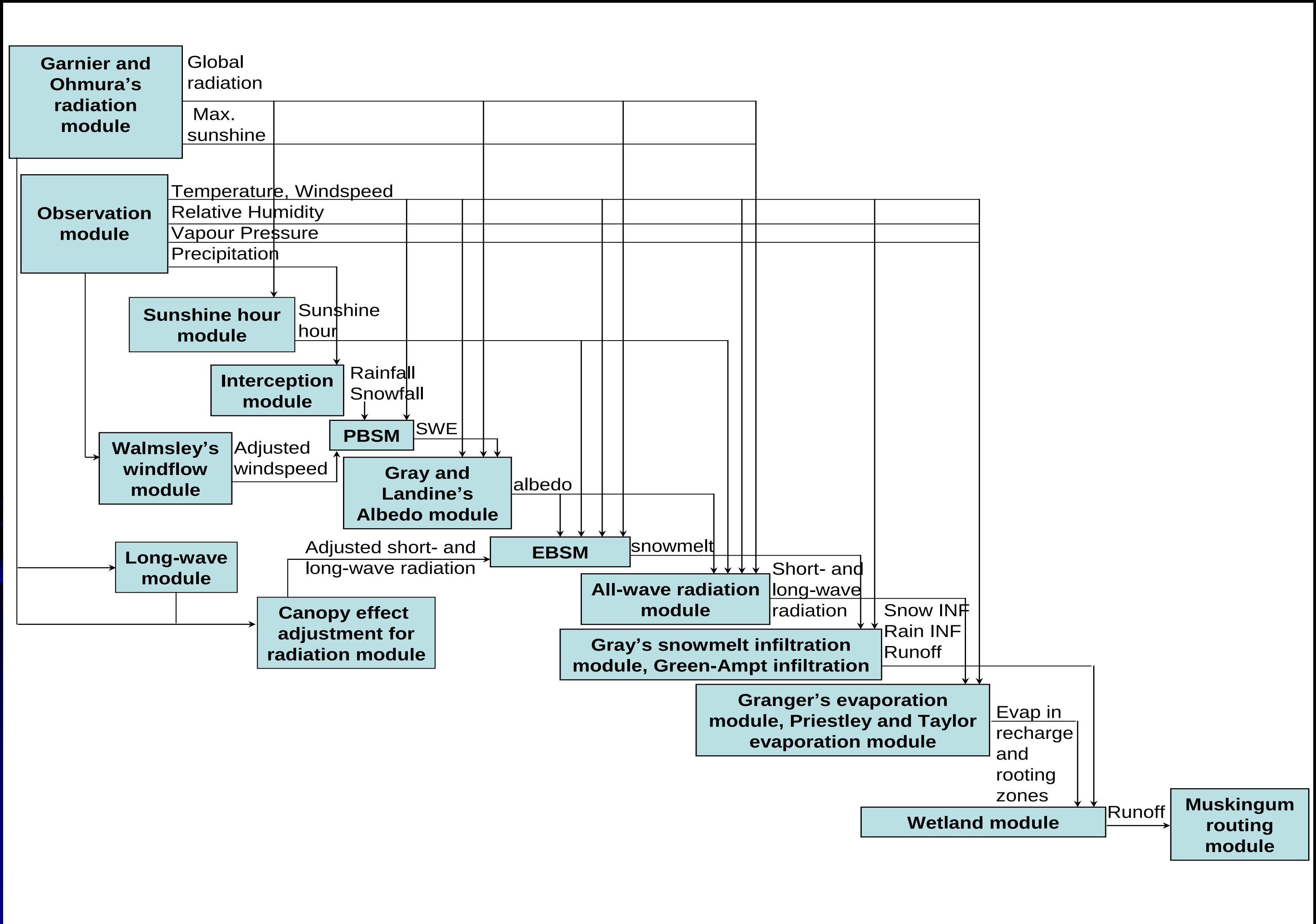
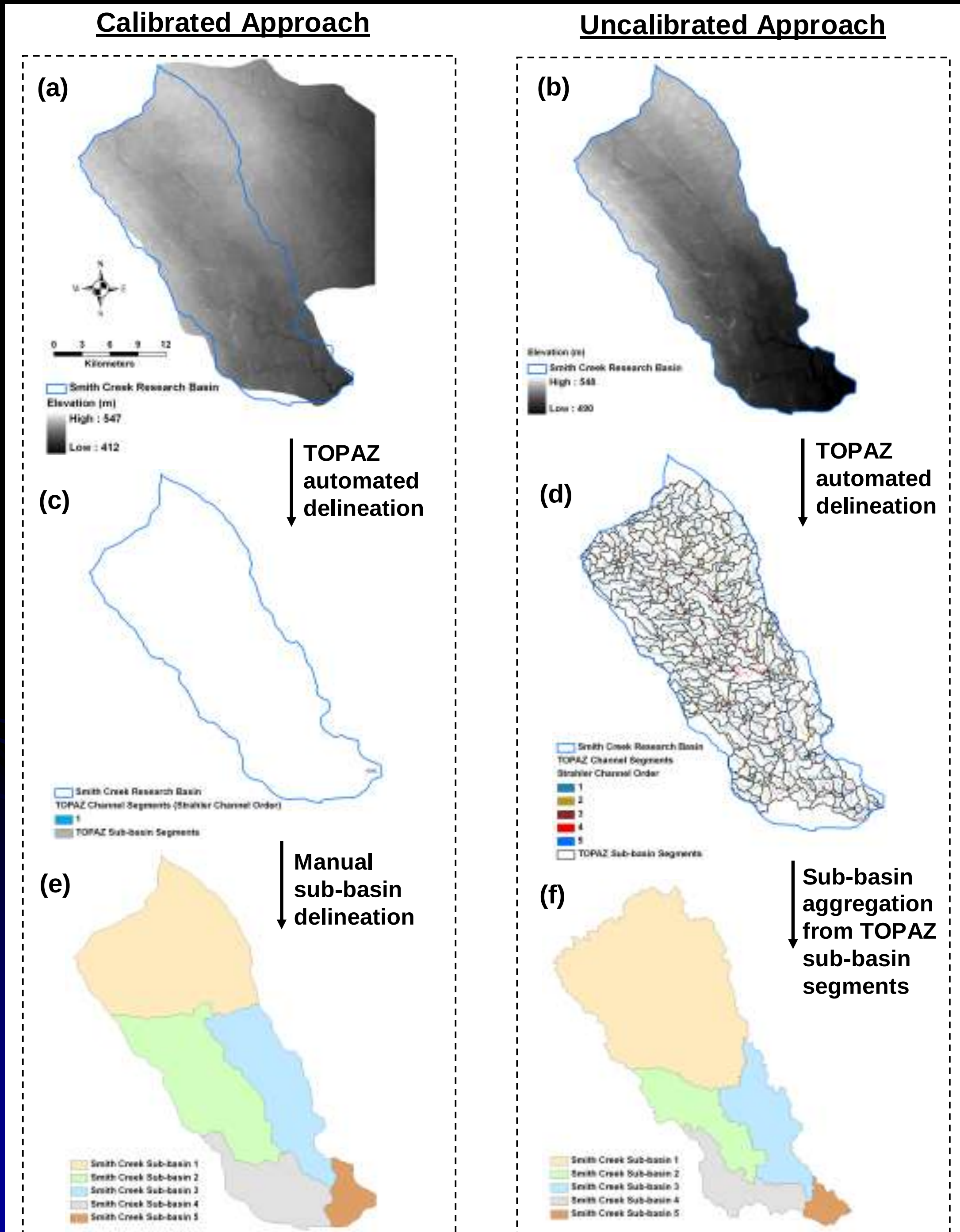


Figure 3. (a) Original 10-m LiDAR DEM, (b) filled depressionless 10-m LiDAR DEM, and (c) "cut/fill" output for Smith Creek basin.

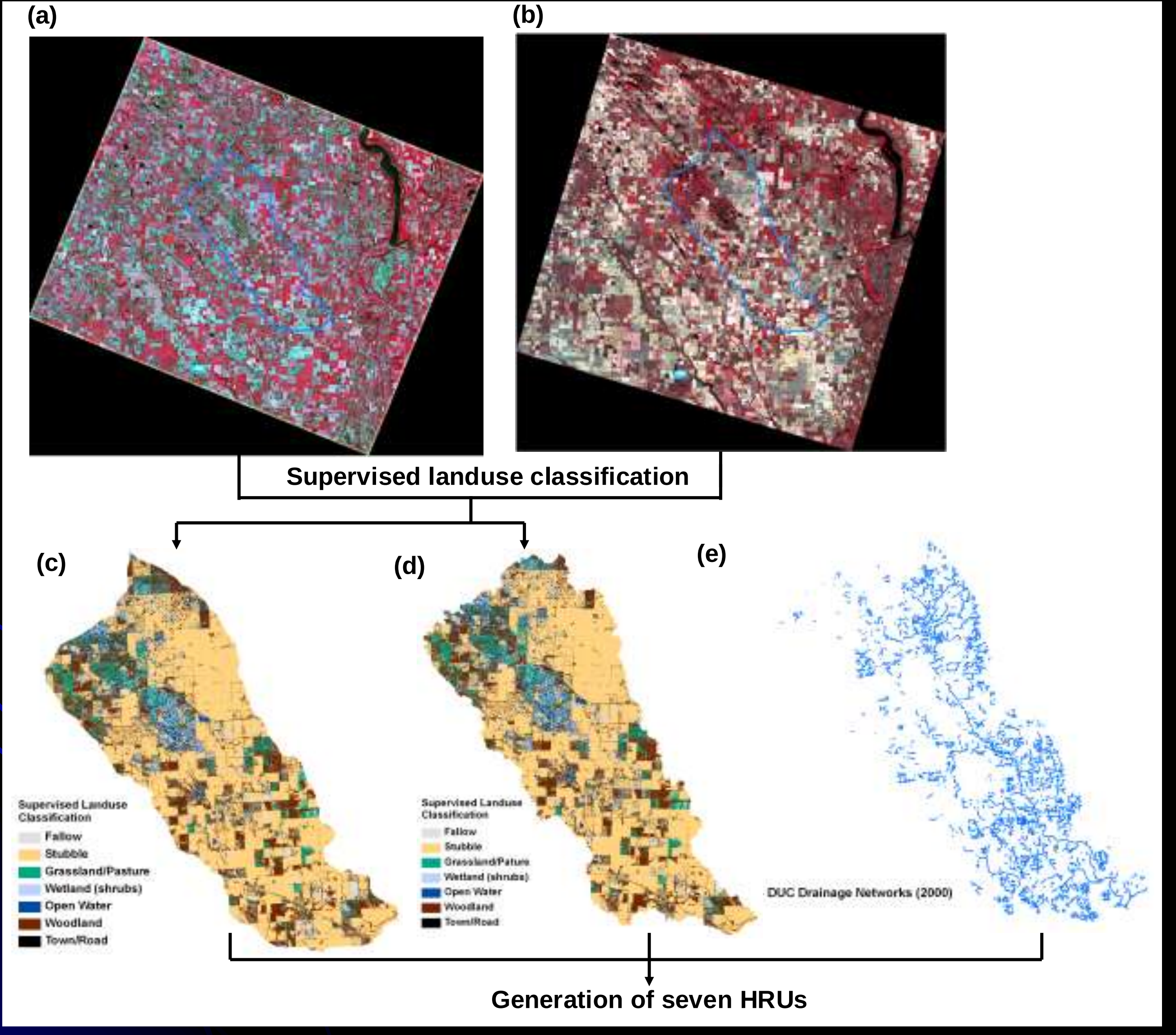
CRHM Prairie Module Structure



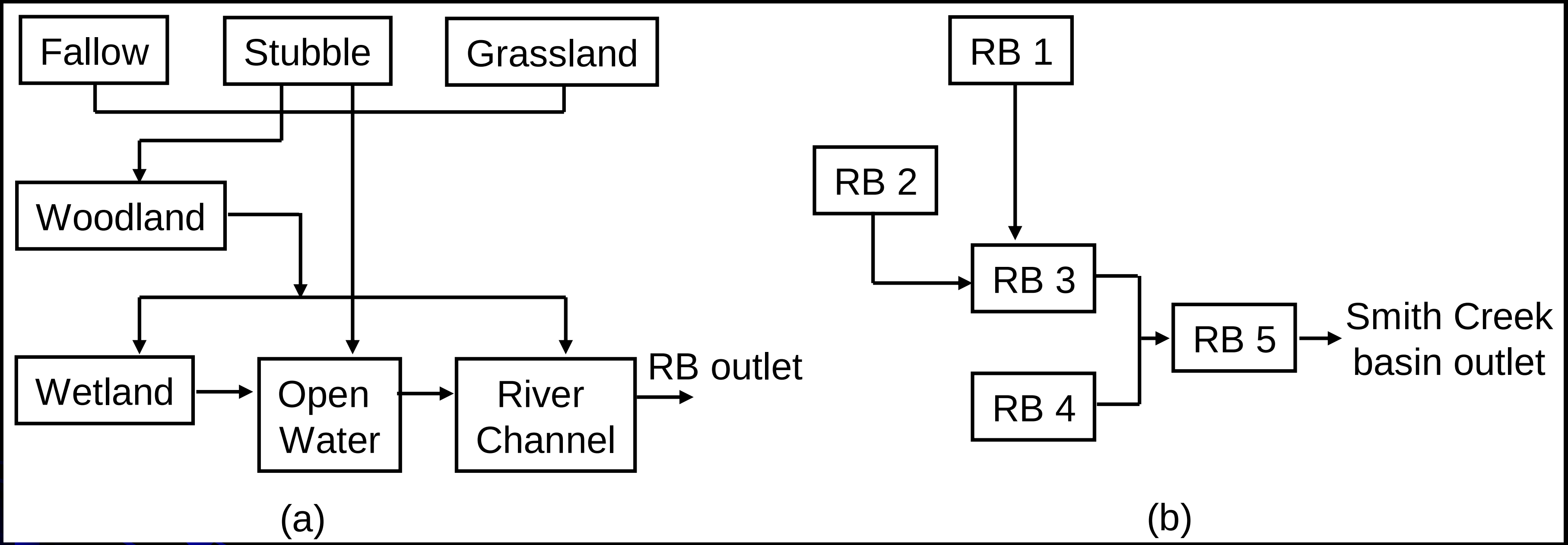


Calibration vs Non-calibrated Modelling using LiDAR

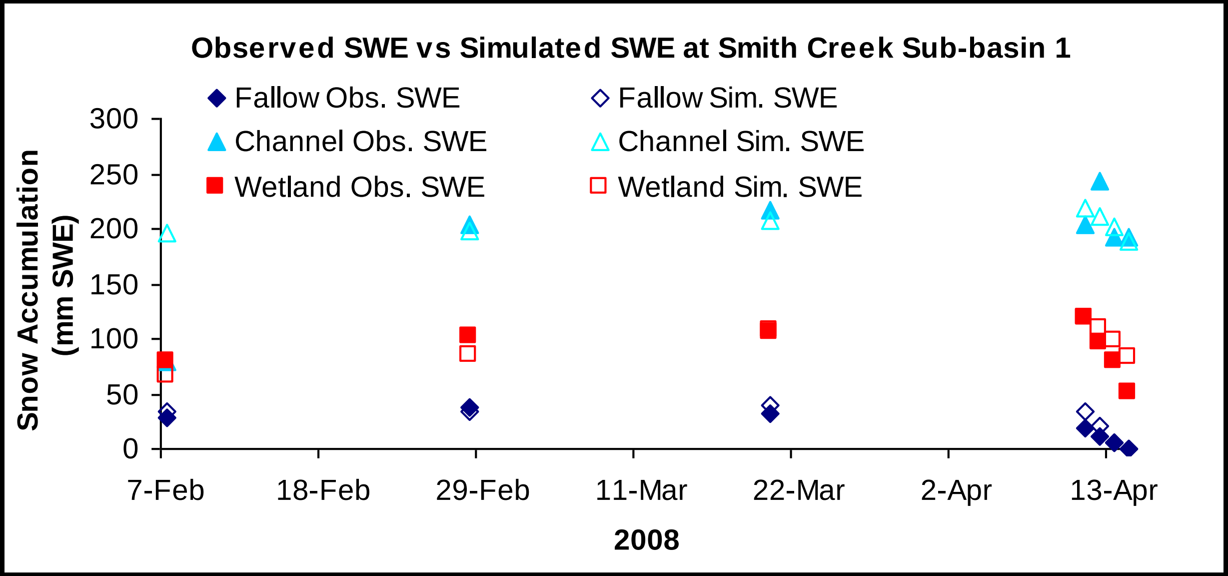
HRU and Basin Delineation

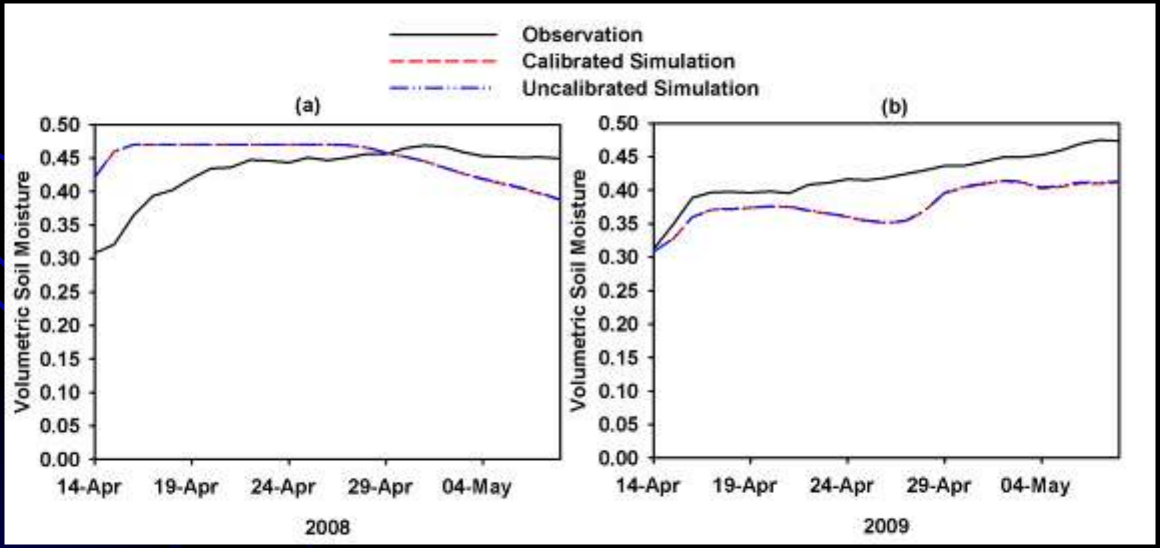


HRU Routing and Sub-basin (RB) Routing

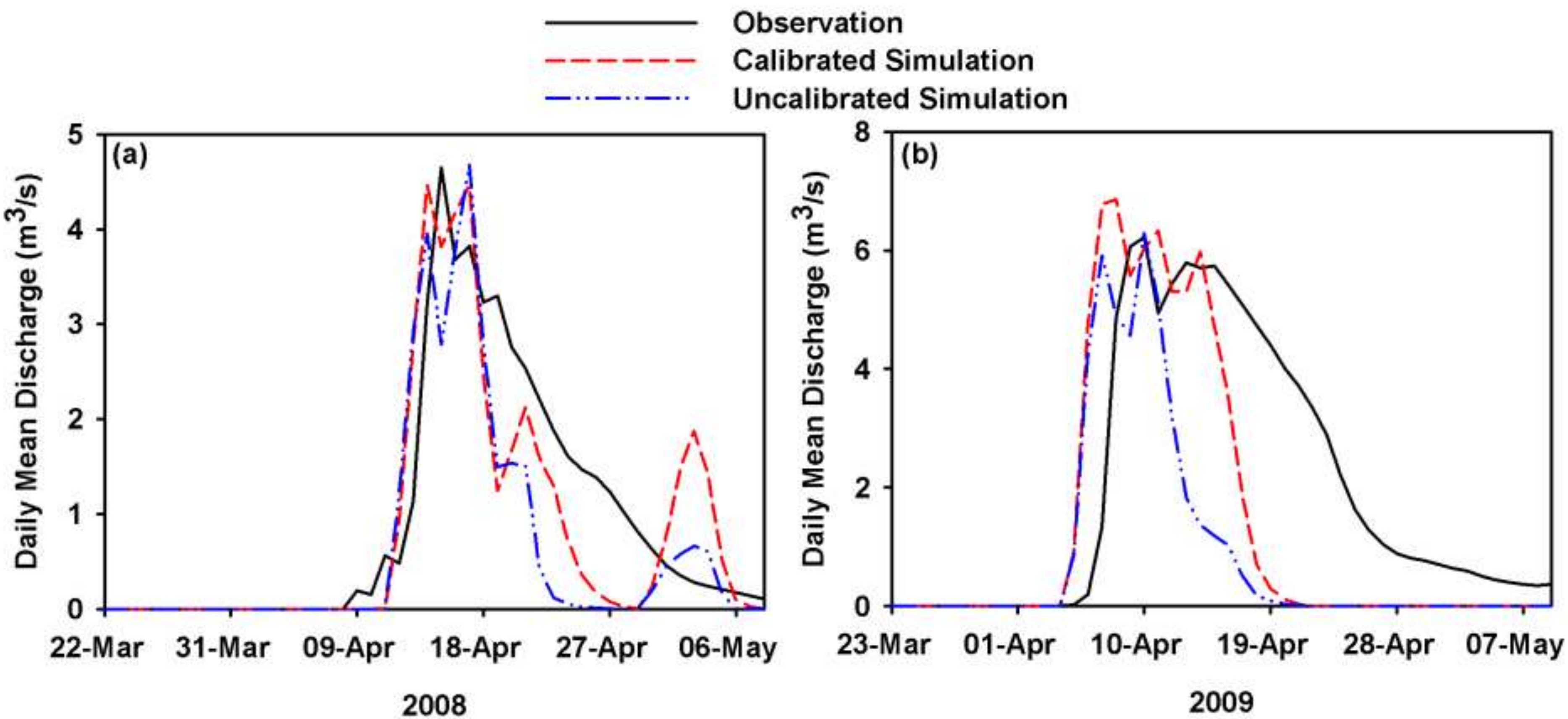


Smith Creek SWE and θ Prediction – No Calibration





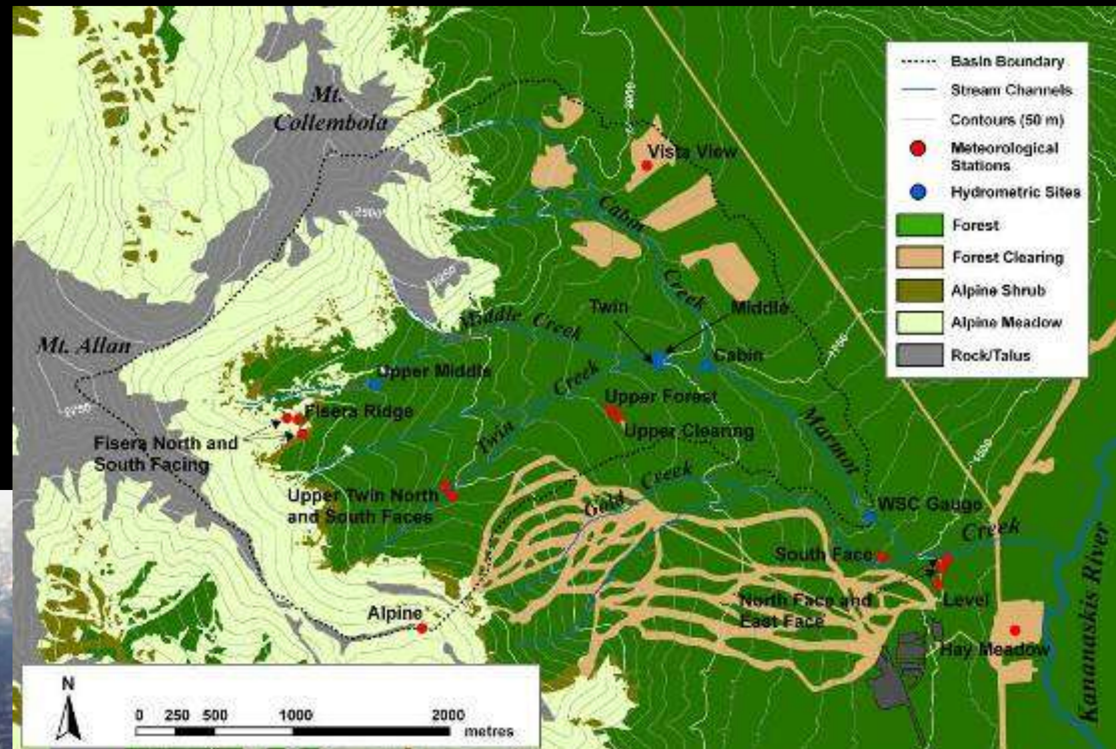
Runoff Prediction: with calibration (no Lidar) and uncalibrated (Lidar DEM for depressional storage)

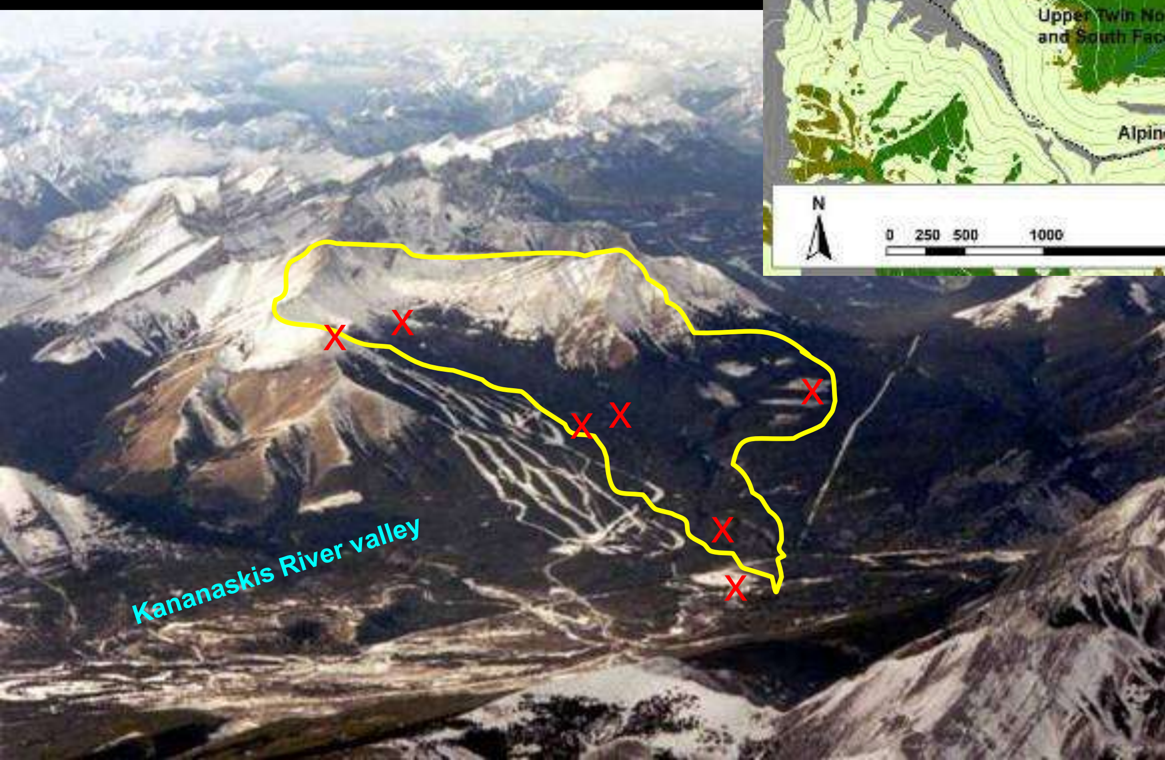


	MB	RMSD (m^3/s	Peak Discharge (m^3/s)
Non-LiDAR Simulation	-0.07	0.10	4.61
LiDAR-based Simulation	-0.39	0.12	4.17
Observation			4.65

	MB	RMSD (m^3/	Peak Discharge (m^3/s)
Non-LiDAR Simulation	-0.21	0.28	7.83
LiDAR-based Simulation	-0.57	0.31	5.37
Observation			6.22

Marmot Creek Research Basin

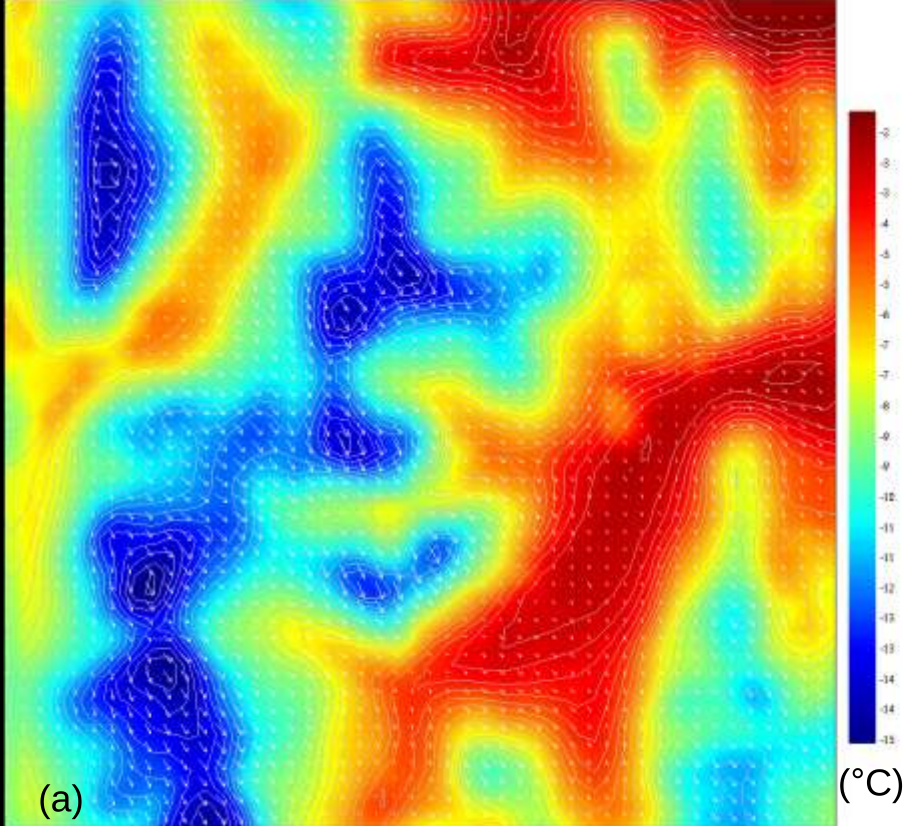


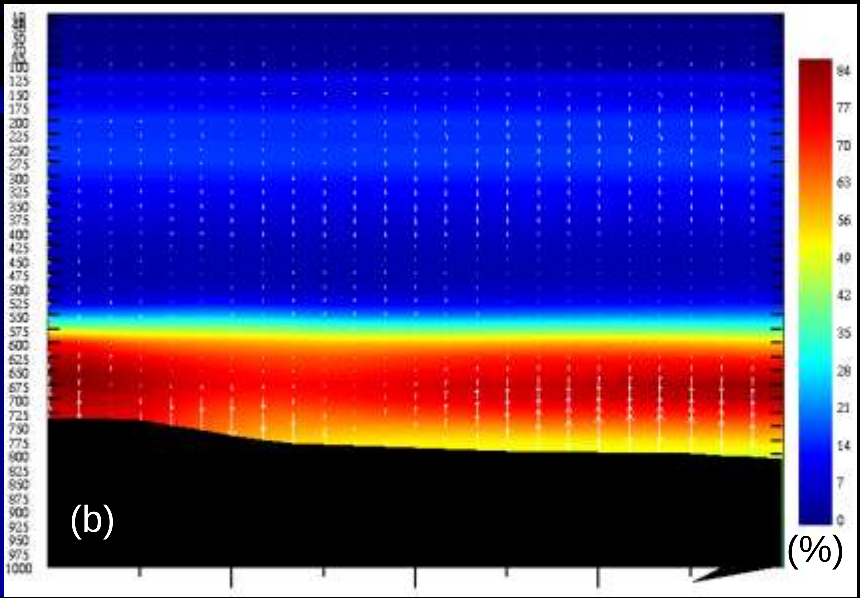


Alpine and Forest Terrain

5/11/2007 00 UTC

GEM-LAM NWP   Grid: 100 m

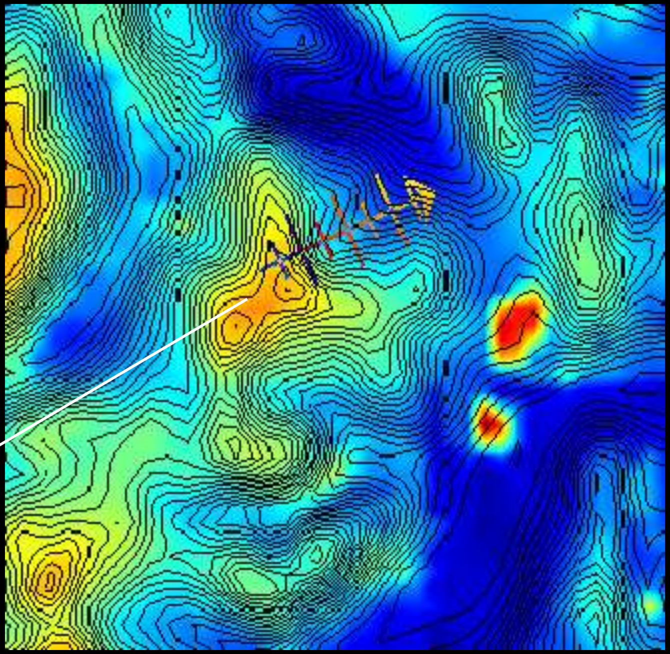




a) Colour: Surface Temperature

Vectors: Wind Field

Contour: Topography



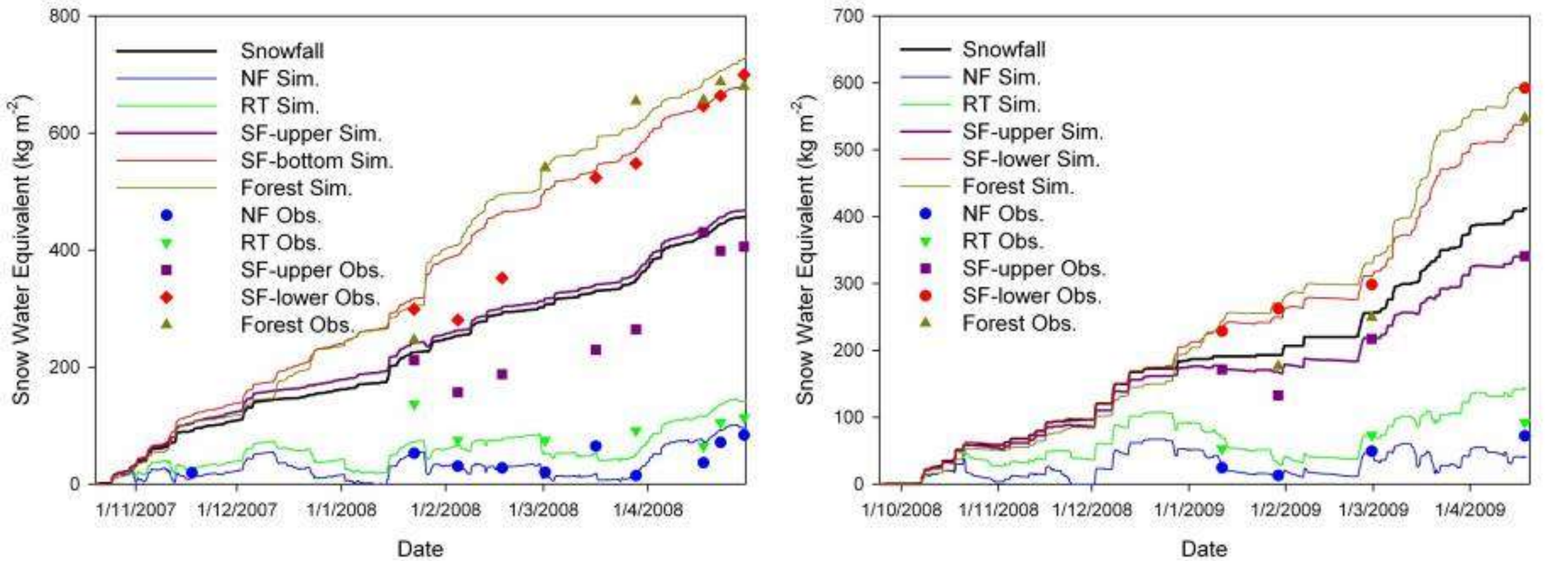
b) Colour: Relative Humidity

Vectors: Wind Field

Black: Topography

Winter Snow Redistribution Modelling

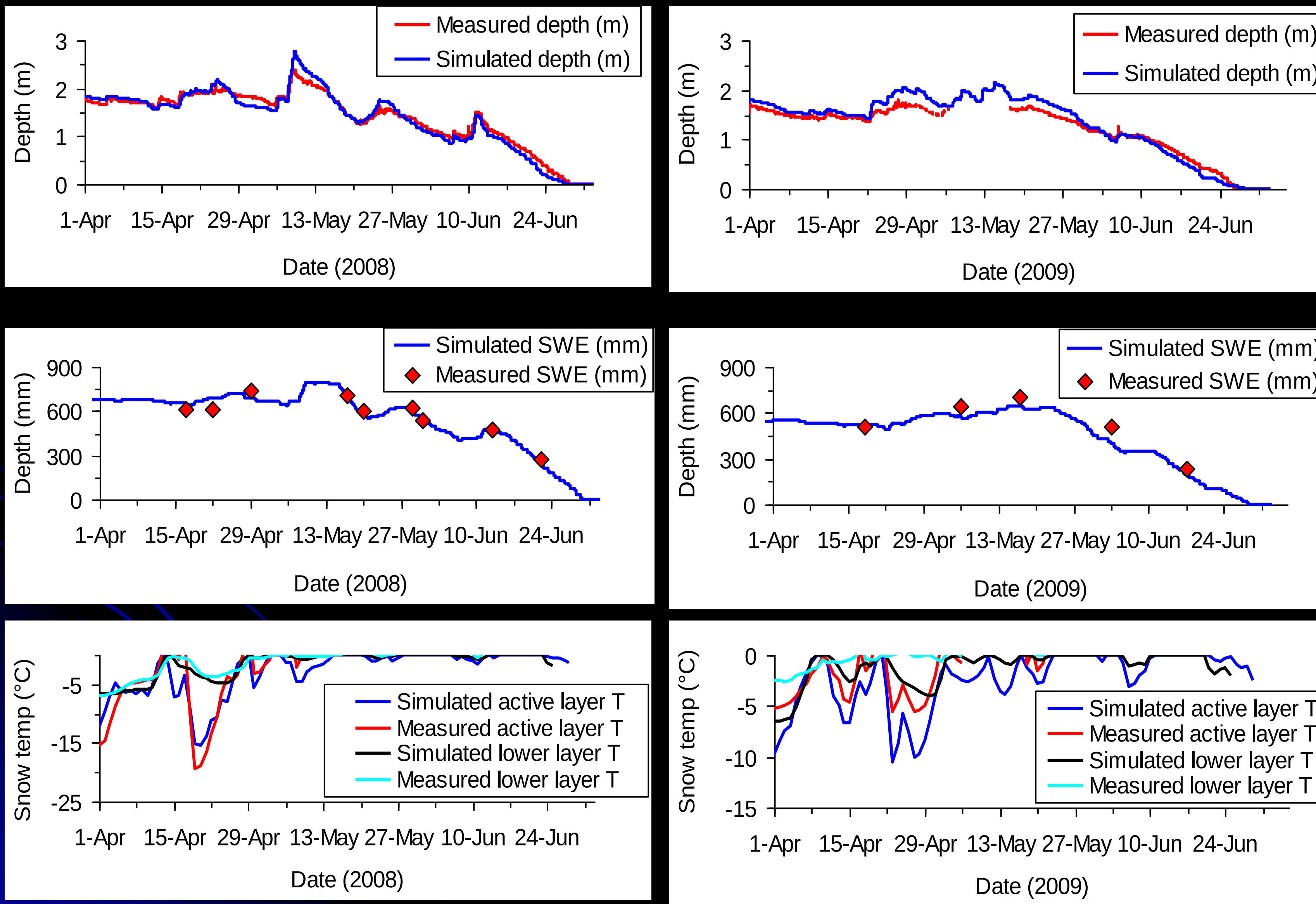
snow blows from north face to south face



	CRHM (PBSM + Snobal)		
Year	***RMSE***	***MB***	***R^2***
2007/2008	13.2	0.13	0.87
2008/2009	5.1	0.05	0.97

Point Evaluation of Snowmelt Model

2008 | 2009

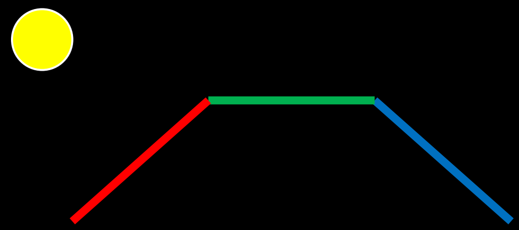


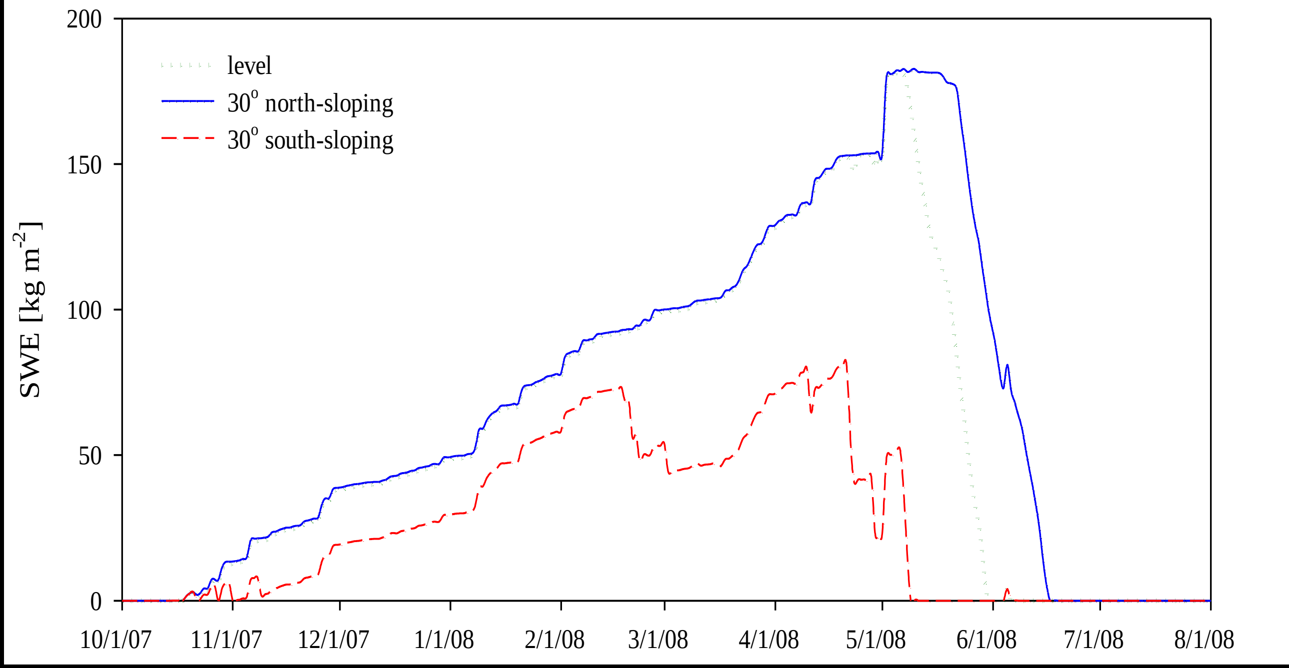
Forest Snow Modelling

Sub-canopy Snowmelt

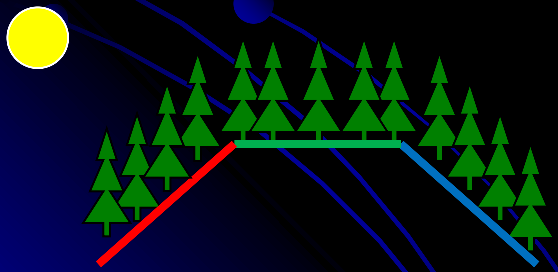
Snow Interception and Sublimation

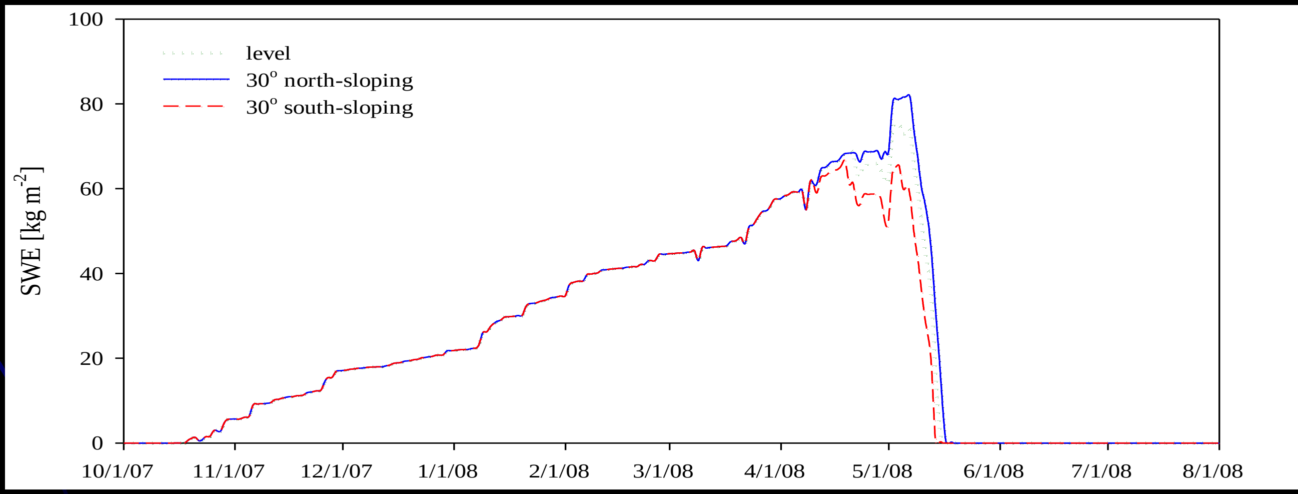
Forest Snow Regime on Slopes



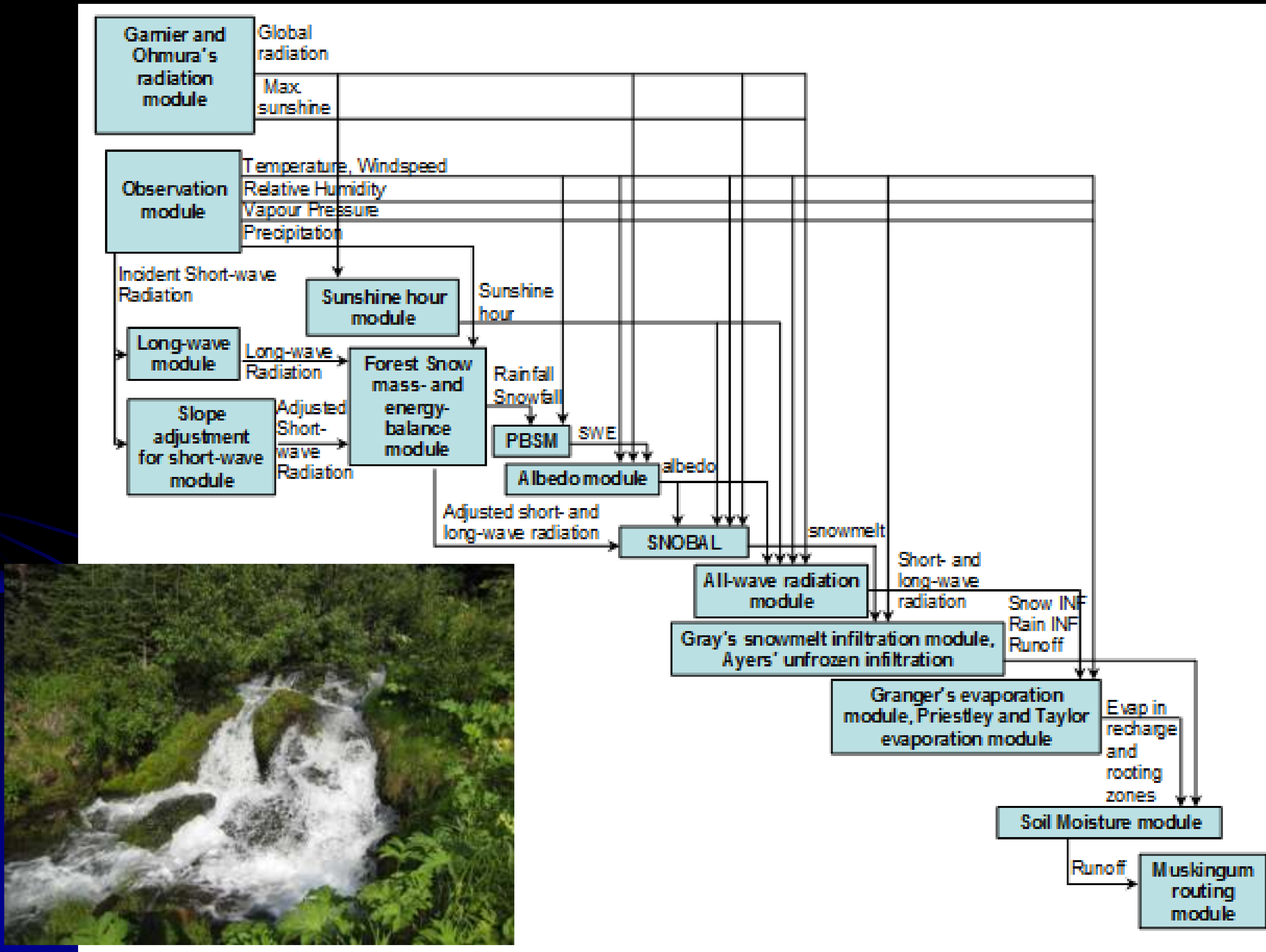


Open slopes highly sensitive to irradiation difference, forests are not

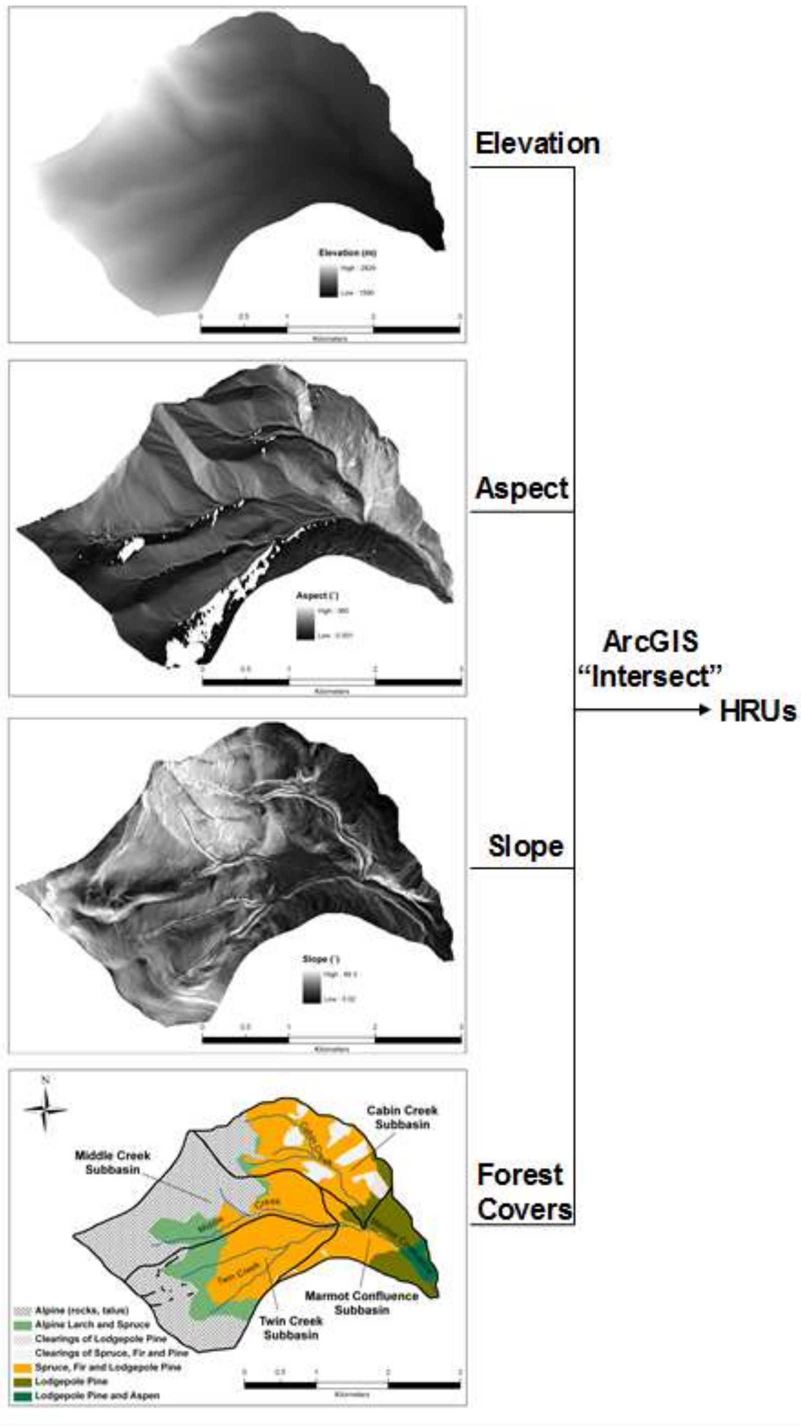




CRHM Mountain Structure

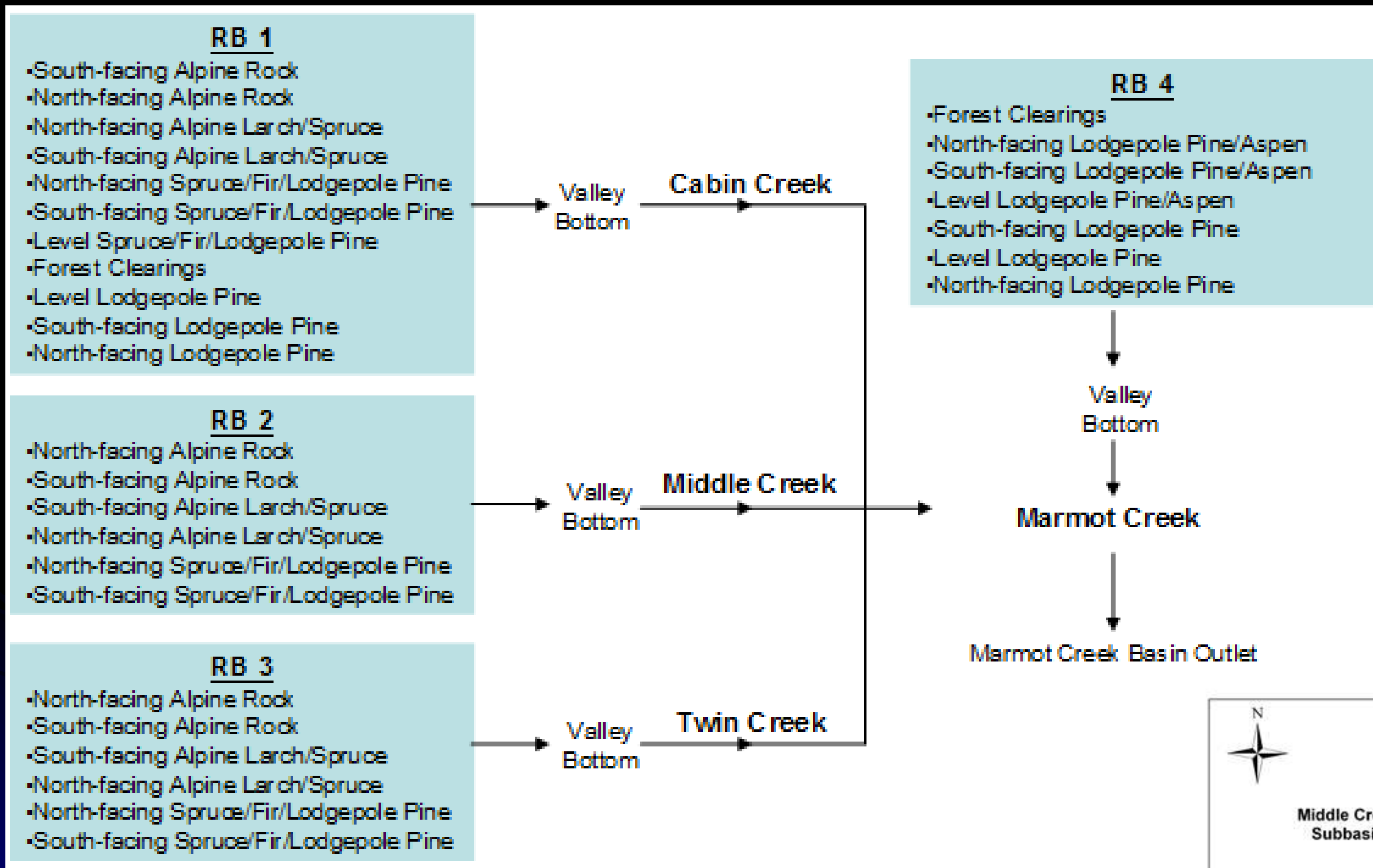


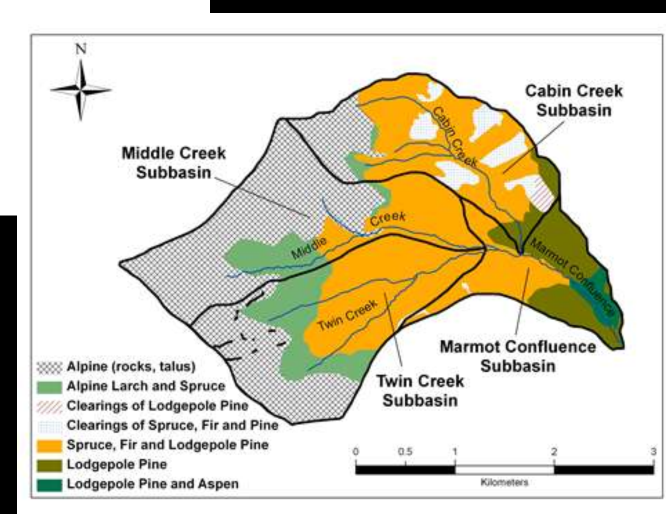
HRU Delineation



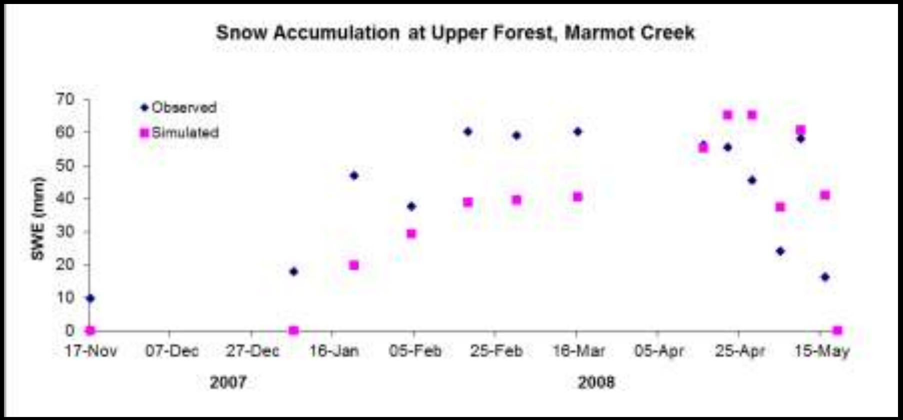
- Driving meteorology: temperature, humidty, wind speed, snowfall, rainfall, radiation
- Blowing snow, intercepted snow
- Snowmelt and evapotranspiration
- Infiltration & groundwater
- Stream network

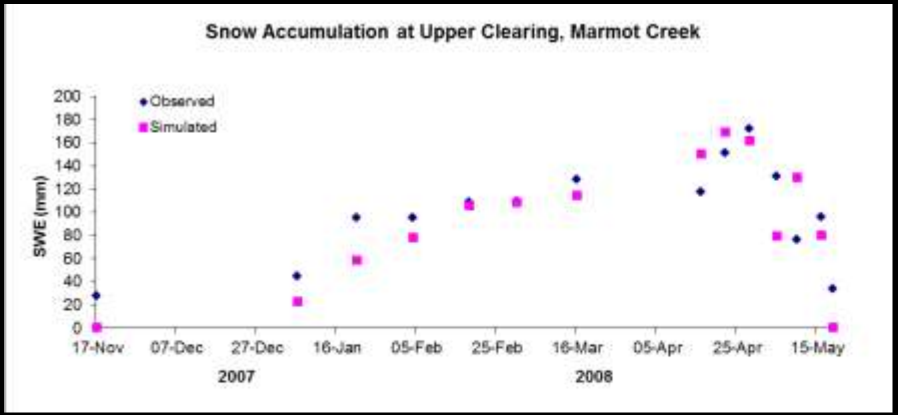
Model Structure

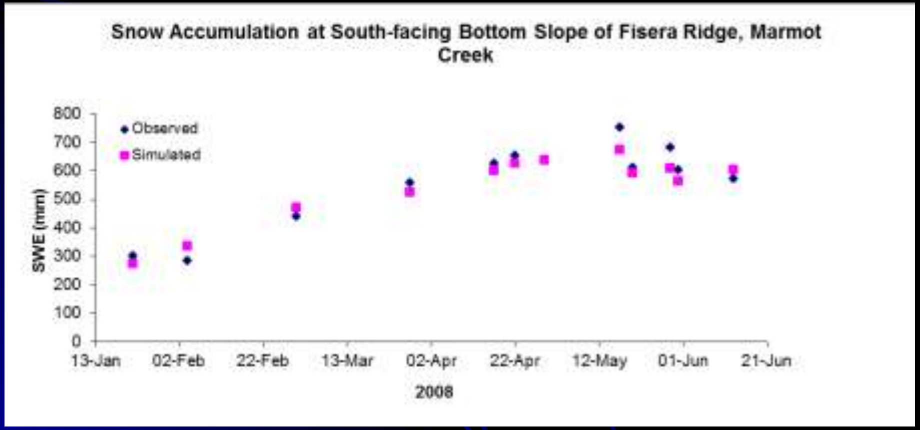


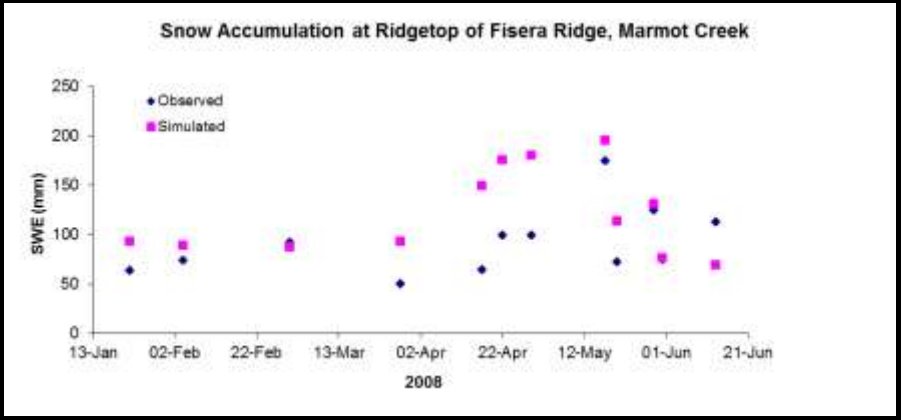


Model Tests - SWE

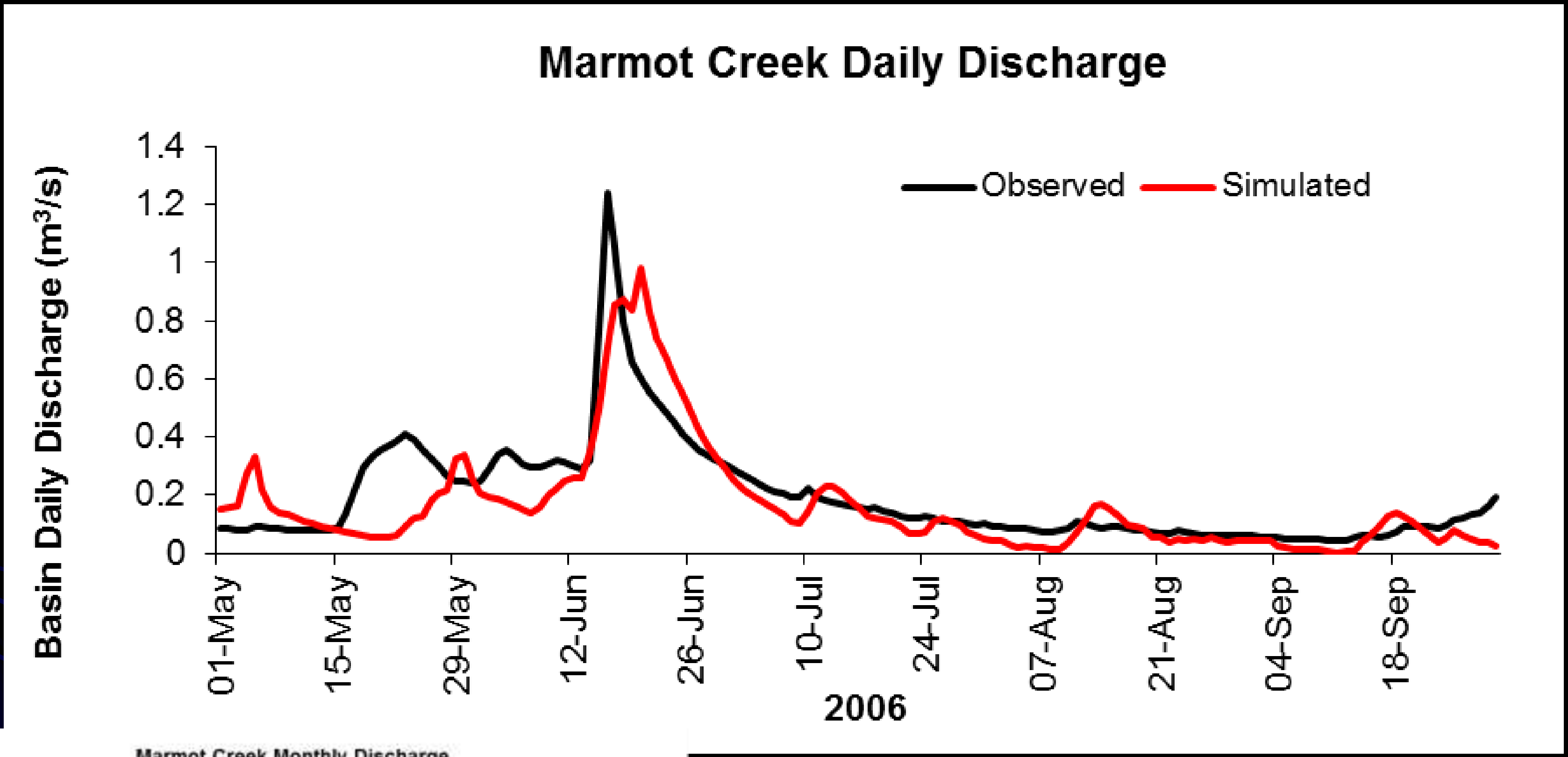


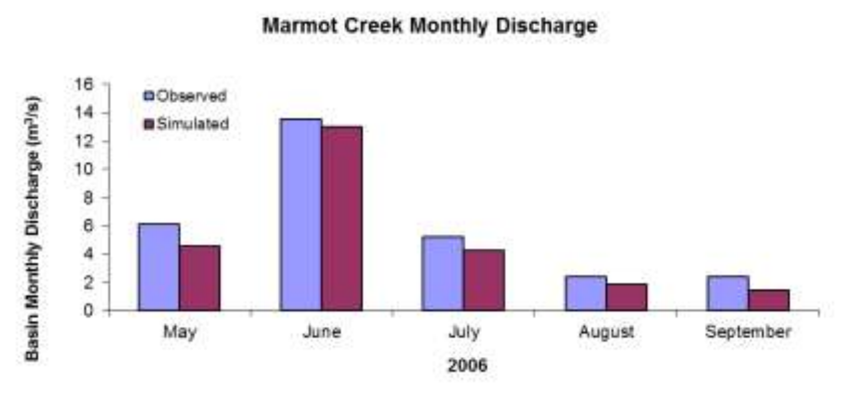






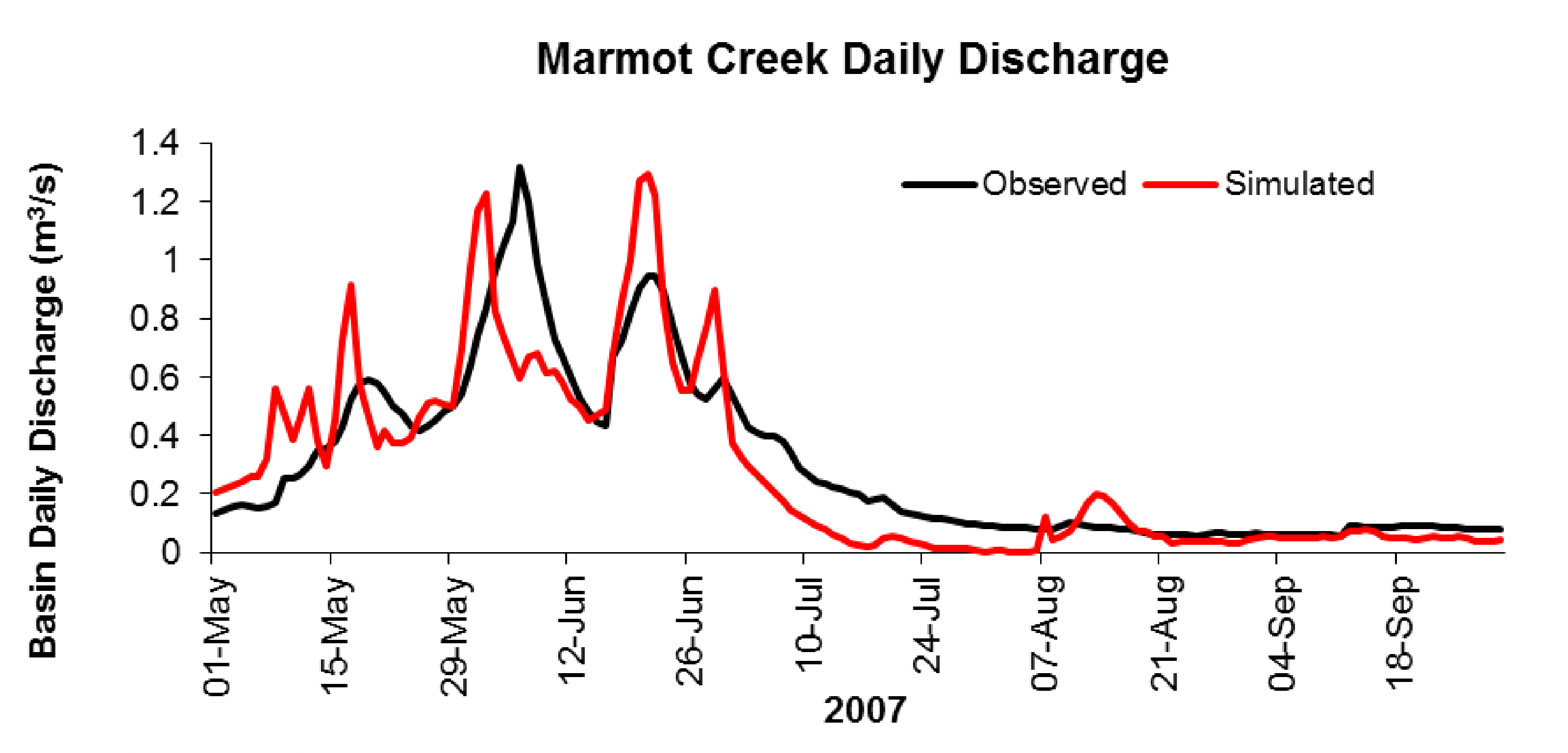
Streamflow Prediction 2006

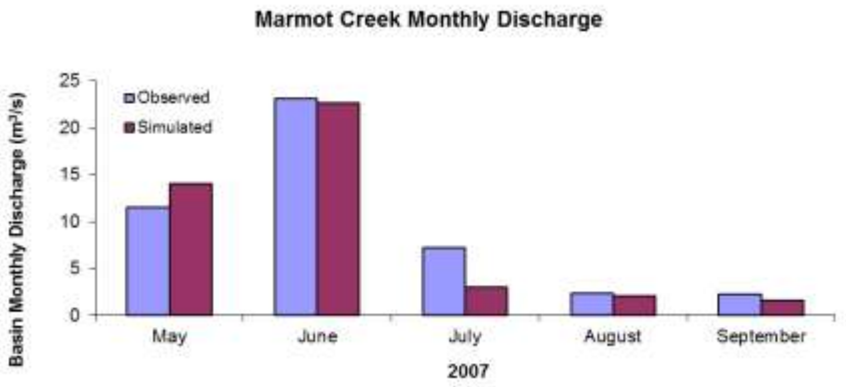




Mean Bias = -0.13
all parameters estimated from basin data

Streamflow Prediction 2007





Mean Bias = -0.068

all parameters estimated from basin data

Hydromythology can be Fought

The perils of calibration with changing hydrology

Victory of understanding over myth

Conclusions

- A variety of process algorithms are available and can be applied in basin scale modelling with data available from standard meteorological stations or from atmospheric models in data poor regions.
- Remote sensing, basic soils information and local research catchments provide the means for discriminating appropriate HRU and defining model structure – these approaches can be extended to data poor regions.
- Remote sensing and process experiments from research basins can be used to parameterise models, reducing the need for calibration from streamflow. Success depends on appropriate model process structure and spatial representation.
- Model structures and parameterisations can be regionalised from research basins for use in ungauged basins with minimal data.
- Streamflow information can still be used to improve model performance in streamflow prediction
  - Diagnostic evaluation of model failure and recommendations for improvement