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Coupled Hydrological Atmospheric Modelling

Alain Pietroniro, Vincent Fortin, Bruce Davison, Brenda Toth, Jessika Toyra, Diana Versegehy, Pierre Pellerin

Environment Canada

ED Souli, N. Kouwen

University of Waterloo

CGEO workshop on soil moisture
June 19-20, Saskatoon

Topics

- Background information
- Development of a coupled model
  - From NWP to MEC and MESH
  - Alphabet soup
- NAESI water availability study
- Some thoughts……………….

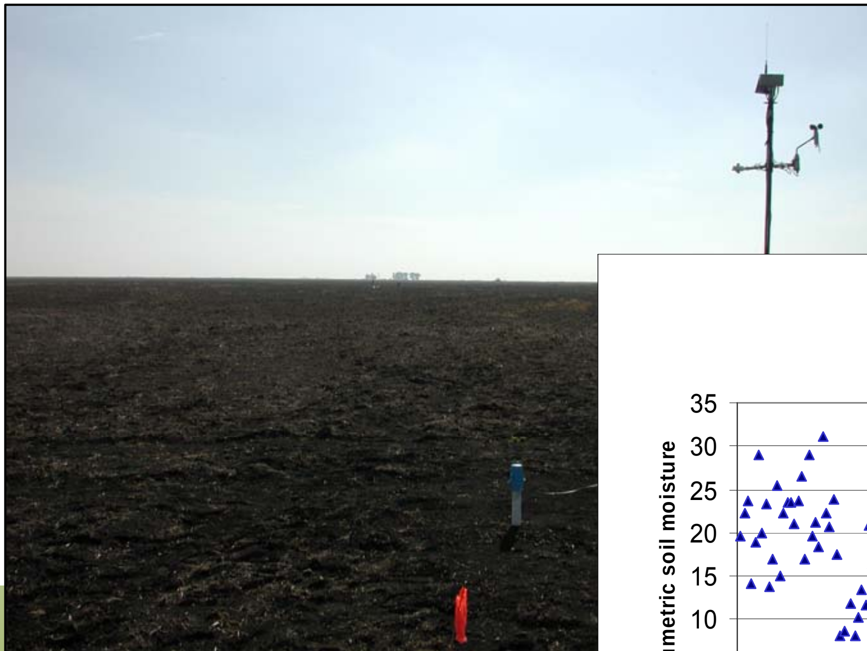
Modelling Water Resources

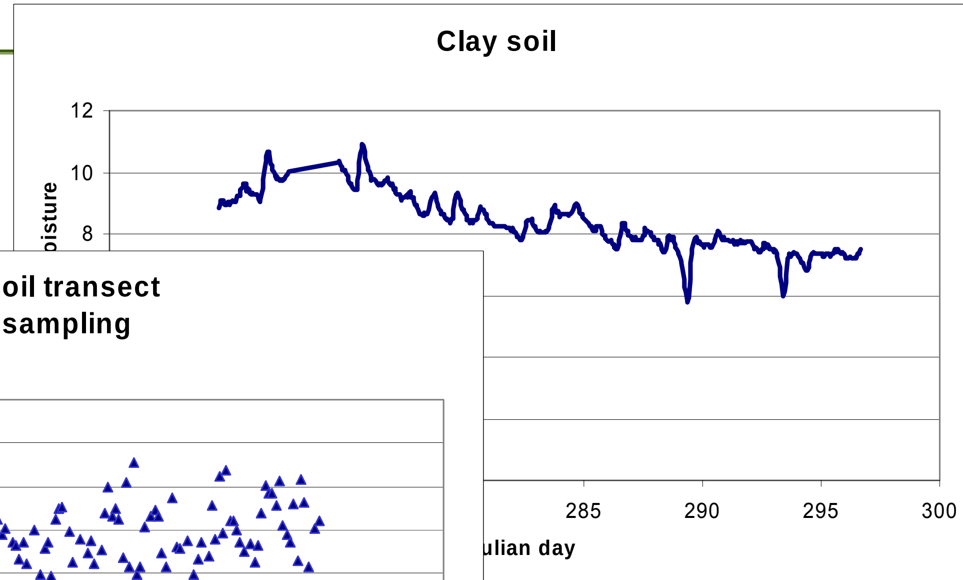
- Hydrologic models are attempts to represent the hydrologic system from precipitation to streamflow in mathematical form.
  - The complexity of the models varies with the user requirements and the data availability.
  - Models vary from simple statistical techniques which use graphical methods for their solution while others include physically-based simulations of the complex three-dimensional nature of a watershed.
  - Always ask - what do I want and how much can I afford ???
    - This often dictates which model is used.
- All models are wrong some are useful
- Never use one model as verification of another

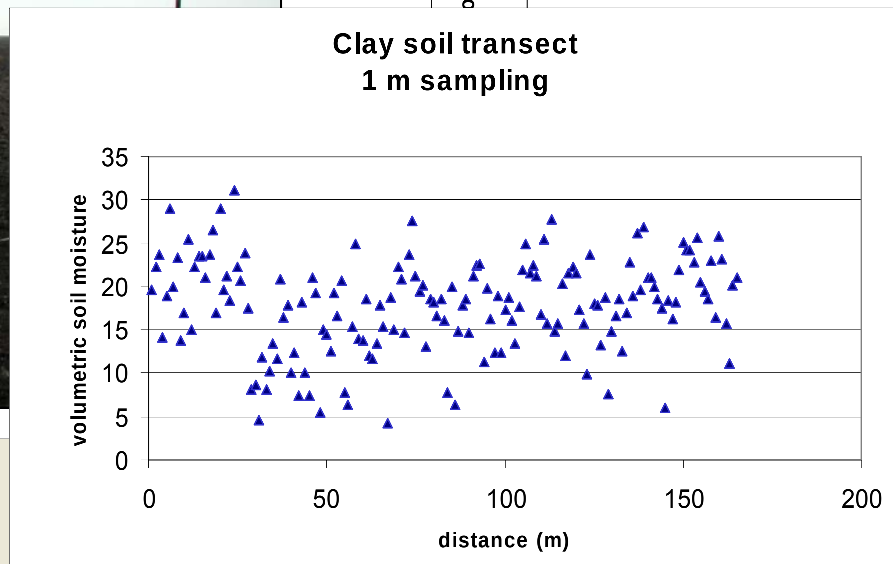
Hydrology Models

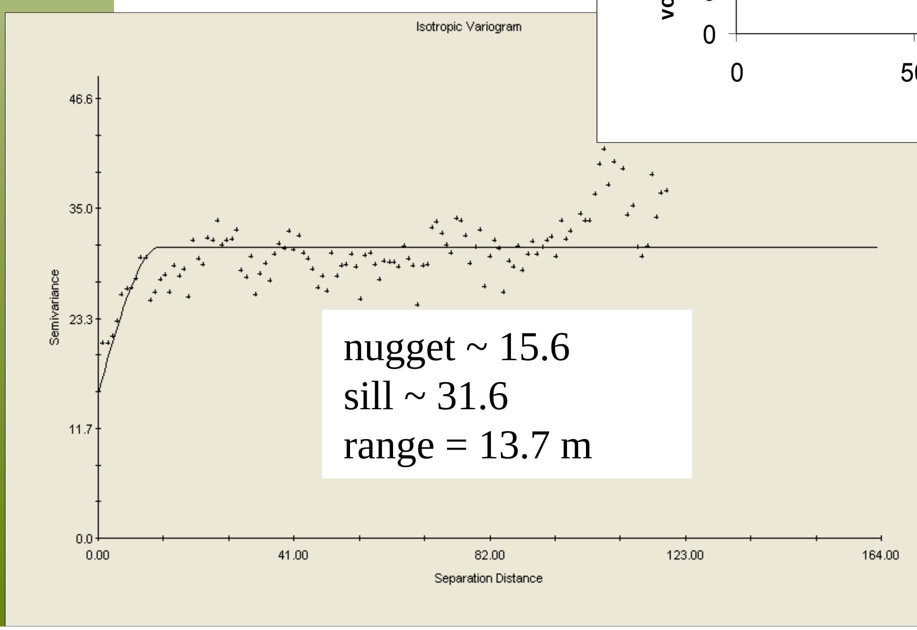
- Heterogeneity of the landscape has forced hydrologist to conceptualize the physics and seek “effective parameters”
  - Focus on effective parameters and precise objective (streamflow)
    - “Equa-finality” is a problem (parameters and models)
      - Get the right answer for the wrong reason
    - REA,GRU,HRU,lumped methods of basin segmentation
    - Buckets to FE PDE’s
    - Difficult to compare different approaches
    - water balance focus
    - Energy Balance not solved for explicitly
  - Lack of consistency in the approach
  - Meteorological Forcing is typically our largest source of error

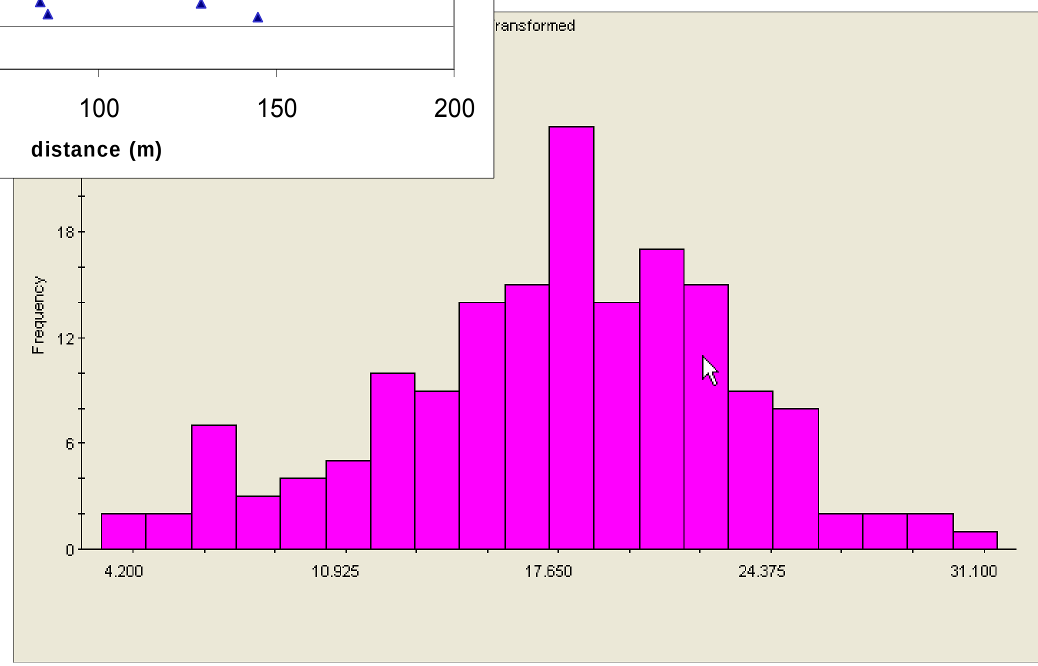
Southern Manitoba (where flat is FLAT) clay soil



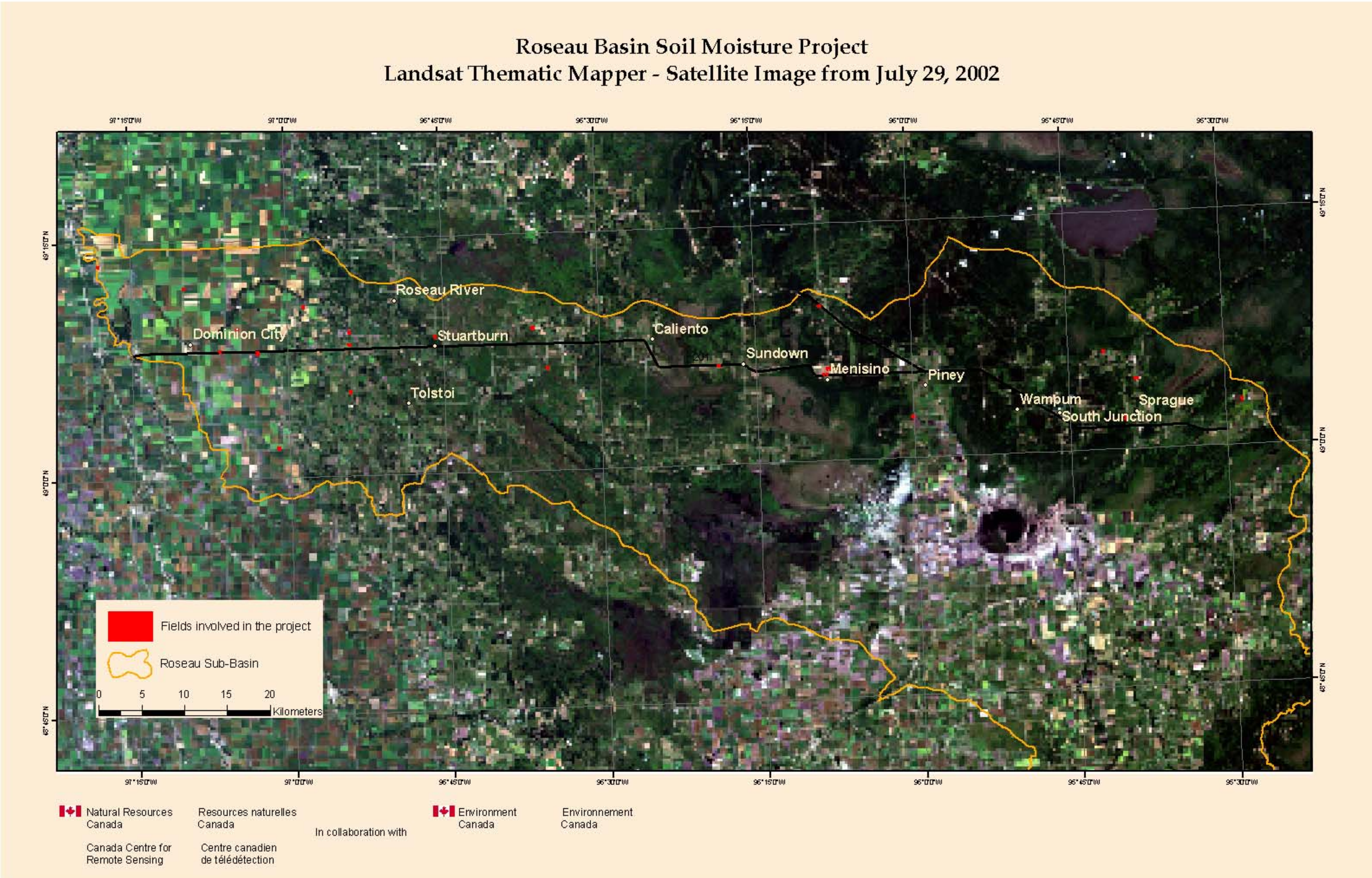








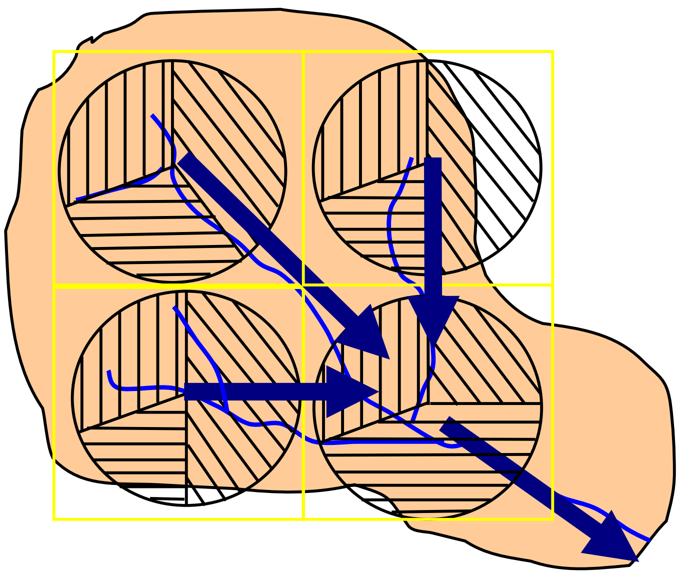
Now what ?

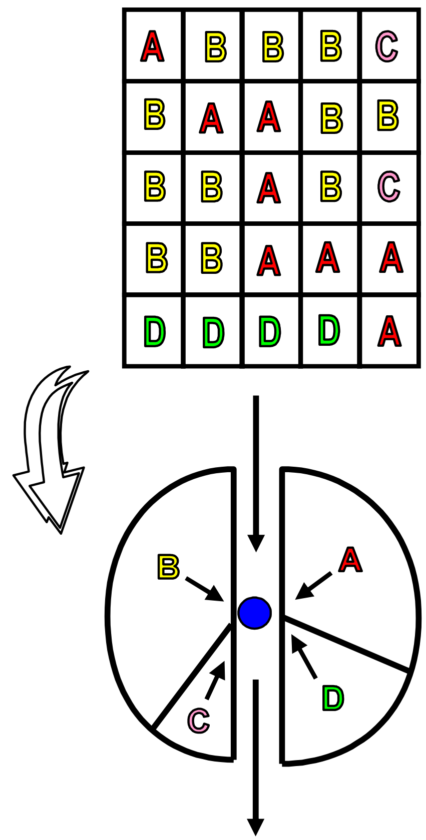


Roseau Basin Soil Moisture Project
Landsat Thematic Mapper - Satellite Image from July 29, 2002
Roseau River
Dominion City
Stuartburn
Caliento
Sundown
Menisino
Piney
Tolstoi
Wampum
Sprague
South Junction
Fields involved in the project
Roseau Sub-Basin
0 5 10 15 20
Kilometers
Natural Resources Canada
Resources naturelles Canada
Canada Centre for Remote Sensing
Centre canadien de télédétection
In collaboration with
Environment Canada
Environnement Canada

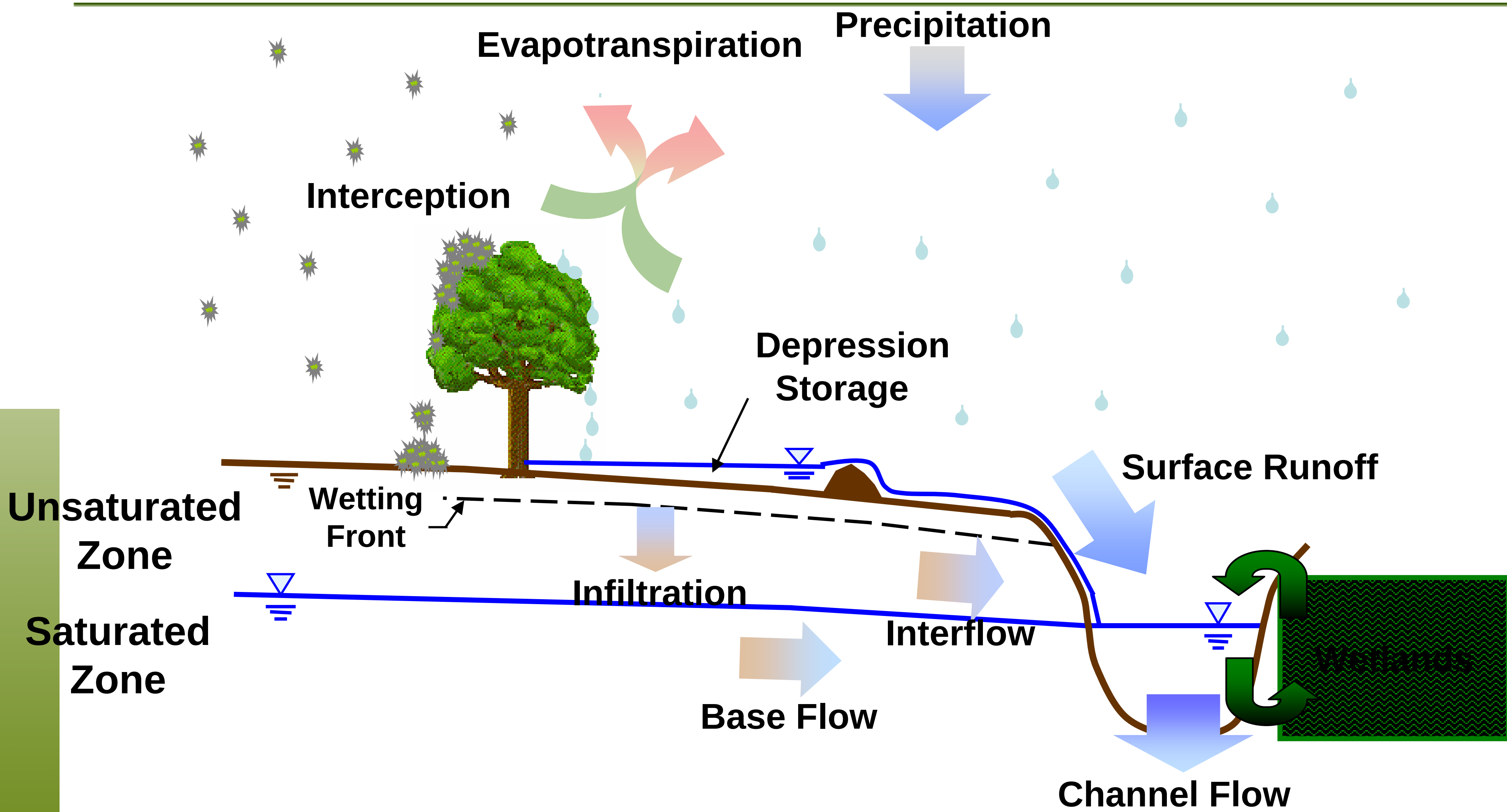
Basin Segmentation using the GRU

- The WATFLOOD/SLURP/MESH model divides a watershed into a number of units known as Grouped Response Units and discritizes the basins into a series of a square grids.
- GRU is consistent in approach to many LSS used in atmospheric models
- The objective in using the GRU is to model hydrologically-consistent subareas of the watershed, each with known properties.





WATFLOOD



Precipitation
Evapotranspiration
Interception
Depression
Storage
Surface Runoff
Unsaturated
Zone
Wetting
Front
Infiltration
Saturated
Zone
Interflow
Base Flow
Wetlands
Channel Flow

Representing Soil Moisture infiltration in the GRU

- WATFLOOD and CLASS use Green-Ampt infiltration Equation

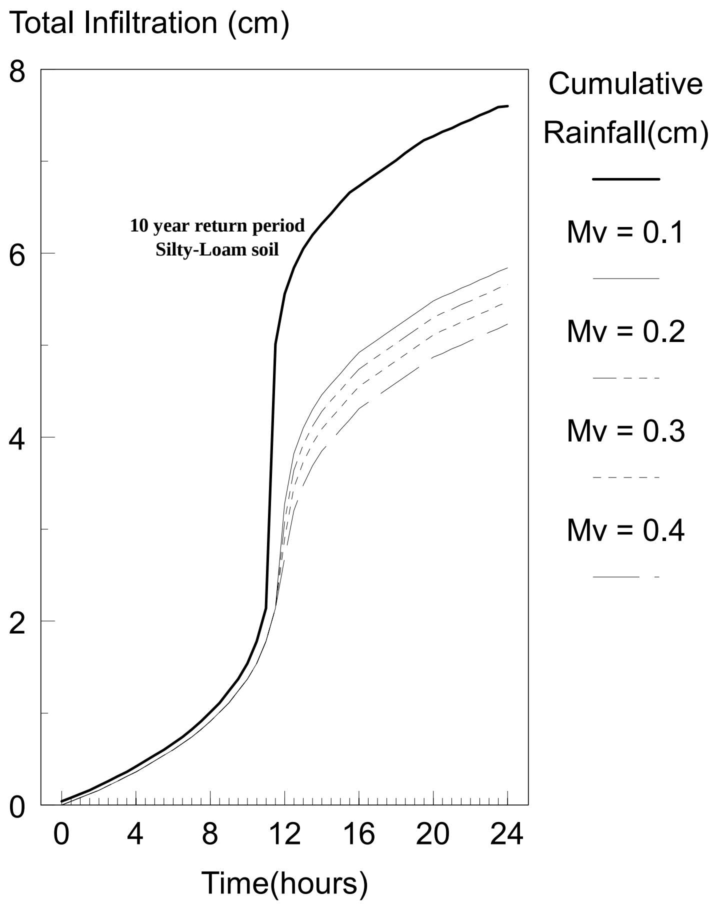
$$F(t) = Kt + \psi_f \Delta\theta \ln\left(1 + \psi_f \Delta\theta F(t)\right)$$

GRU conceptual framework requires :

•Requires physical properties of soil for parameterization – based on optimization for each GRU.

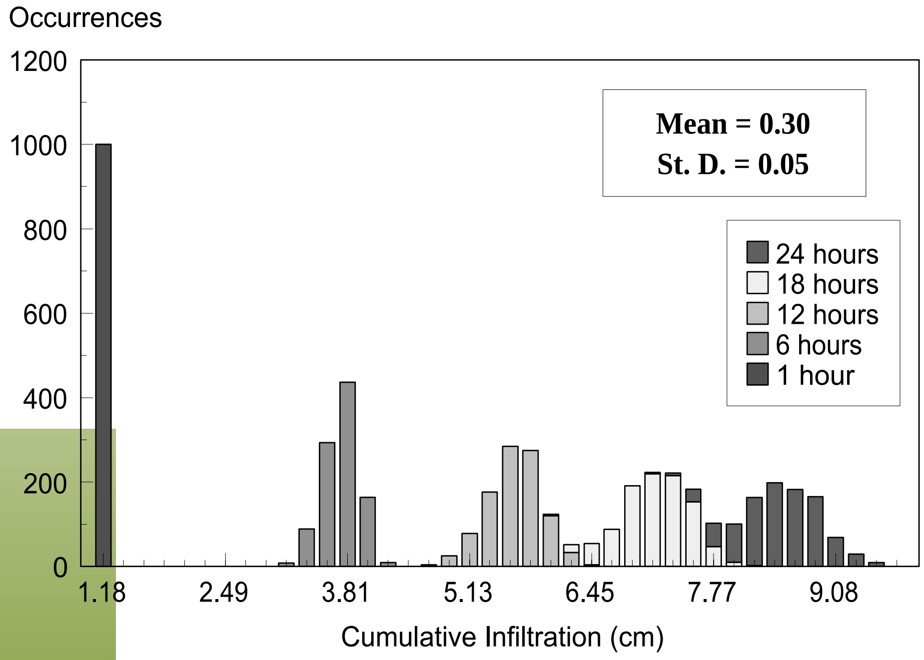
•Requires initial soil moisture for each GRU (or tile)

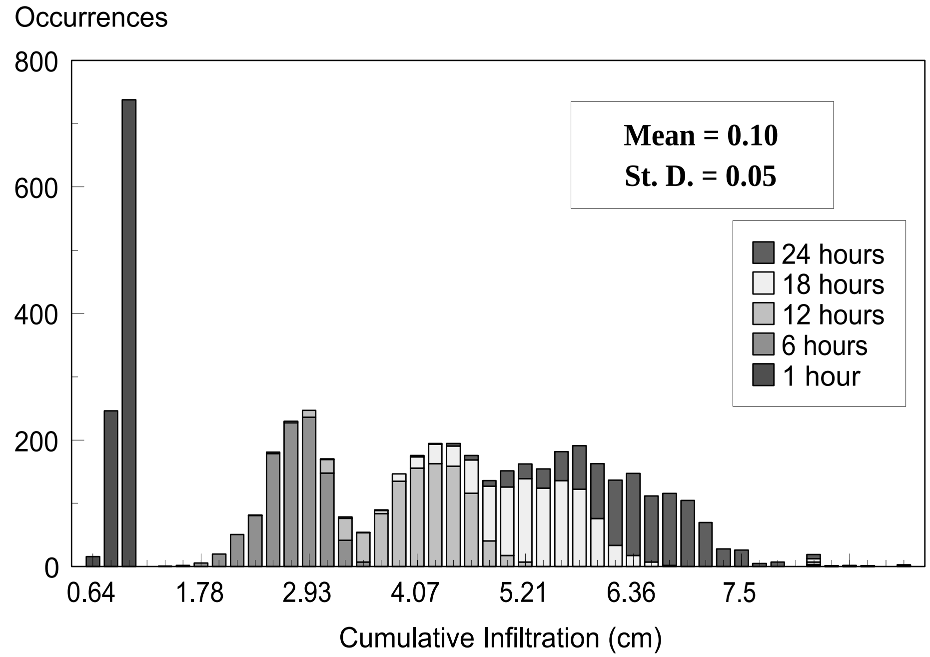
Green-Ampt - Cumulative infiltration for 10-year design storm



	Initial volumetric moisture					
	0.1	0.15	0.2	0.25	0.3	0.35
Sand	7.59	7.59	7.59	7.59	7.59	7.59
Loamy Sand	4.82	7.03	6.9	6.77	6.63	6.48
Sandy Loam	6.02	5.93	5.83	5.72	5.62	5.5
Loam	4.94	4.89	4.75	4.67	4.63	4.51
Silt Loam	5.85	5.76	5.67	5.57	5.47	5.37
Sandy Clay Loam	4.66	4.54	4.40	4.23	4.00	3.66
Clay Loam	4.39	4.3	4.17	4.03	3.78	3.61
Silty Clay Loam	4.60	4.37	4.37	4.13	4.06	3.79
Sandy Clay	3.93	3.61	3.63	3.4	3.16	2.83
Silty Clay	4.00	3.81	3.76	3.59	3.27	3.12
Clay	3.54	3.37	3.19	3.05	2.81	2.49

Monte Carlo Analysis of distributed initial conditions

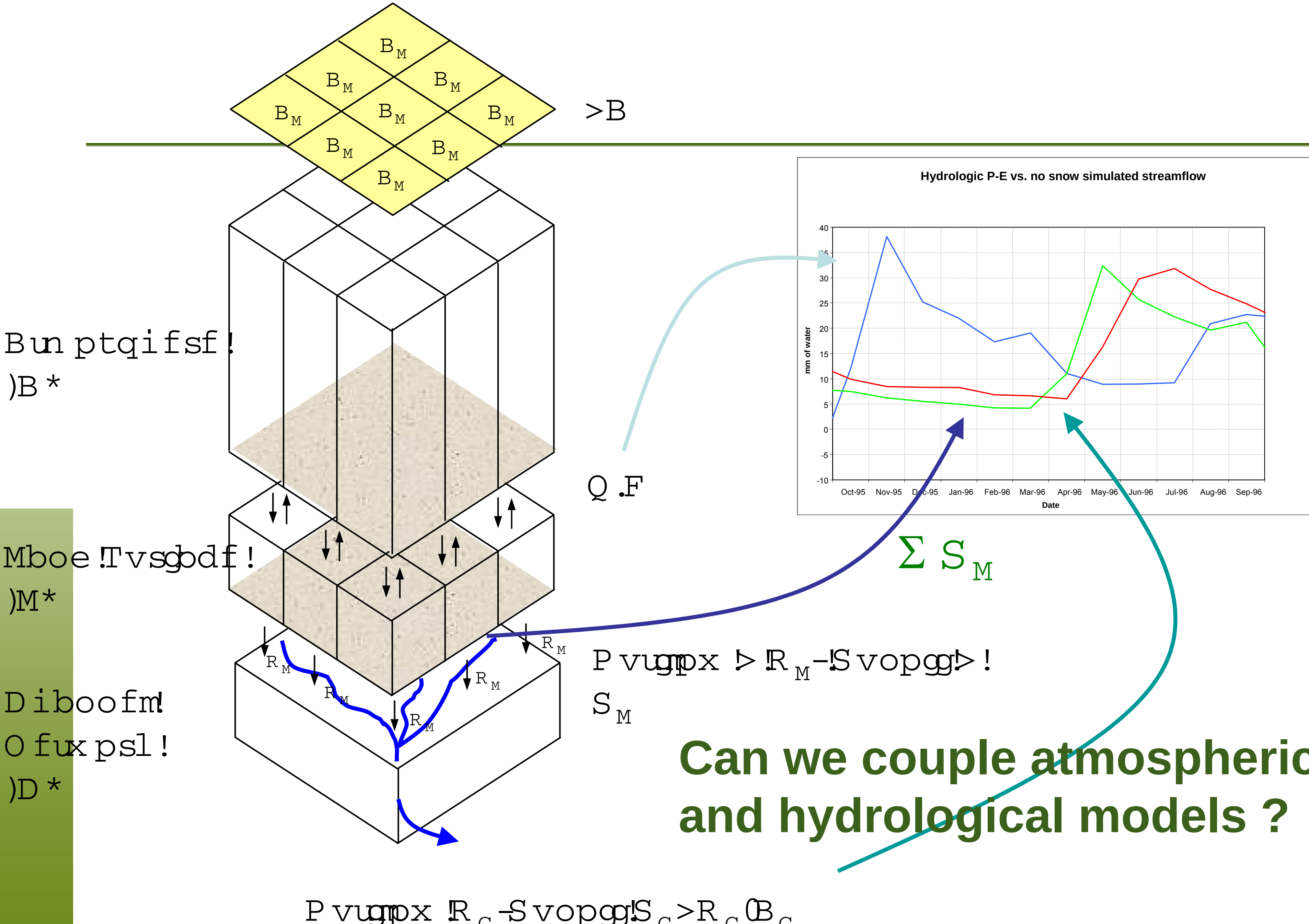




Soil Type	*Initial Conditions*		*Total 24 hour Infiltration*	
	Mean	Standard Deviation	Point Simulation	Distributed Simulation
			Infiltration (cm)	Mean Infiltration (cm)
Constant Rainfall (1 cm/hr for 24 hrs)				
Loam	0.1	0.05	13.16	13.17
Loam	0.2	0.05	12.27	12.27
Loam	0.3	0.05	11.19	11.18
Loam	0.4	0.05	9.75	9.72
Loam	0.1	0.1	13.16	13.15
Loam	0.2	0.1	12.27	12.23
Loam	0.3	0.1	11.19	11.1
Loam	0.4	0.1	9.75	9.82
Silty Clay Loam	0.1	0.05	8.54	8.55
Silty Clay Loam	0.2	0.05	7.58	7.58
Silty Clay Loam	0.3	0.05	6.41	6.40
Silty Clay Loam	0.4	0.05	4.81	4.71
Silty Clay Loam	0.1	0.1	8.54	8.53
Silty Clay Loam	0.2	0.1	7.58	7.53
Silty Clay Loam	0.3	0.1	6.41	6.27
Silty Clay Loam	0.4	0.1	4.81	4.73

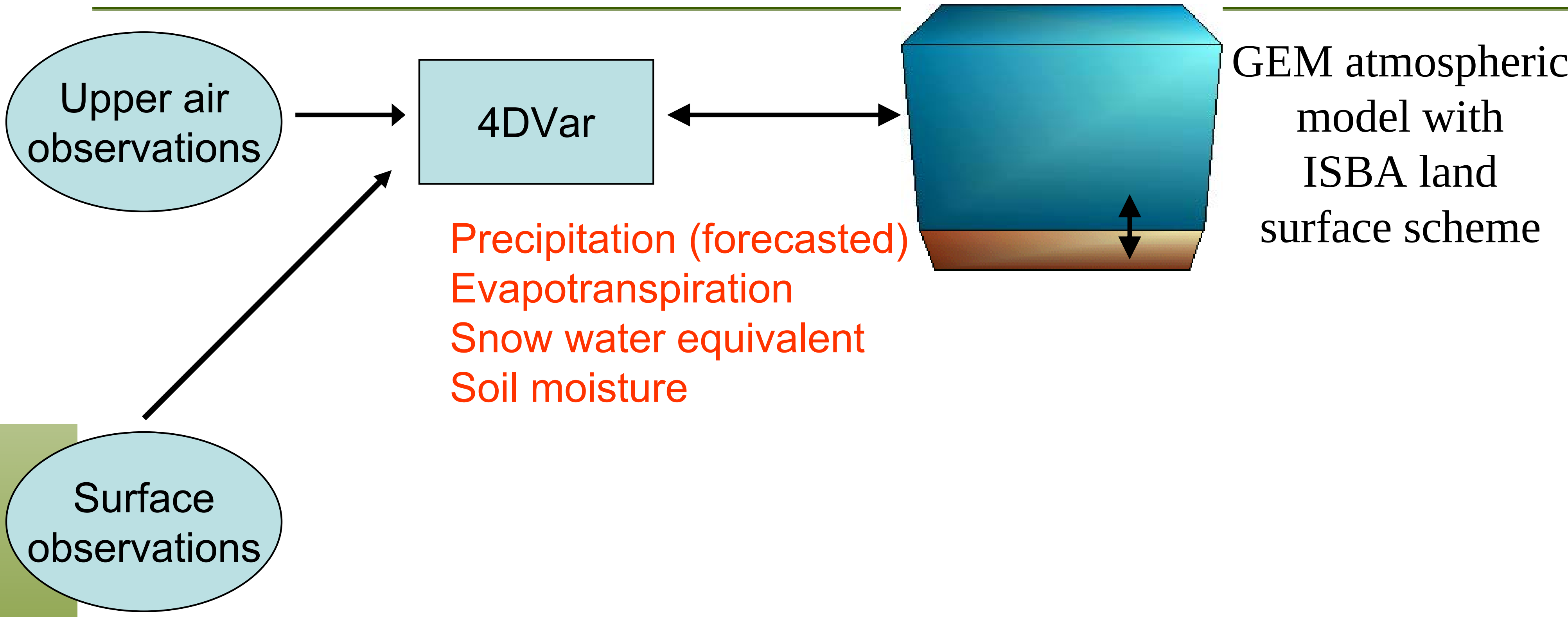
The GRU or TILE concept

- Links the micro-scale to meso-scale.
- Computational element includes the many tiles that generate run-off.
- Mean initial condition can be established by tile
- All tiles within a grid are subject the same meteorological forcing.
- Grouped according to hydrological response.
- Each has its own connection to the channel system.

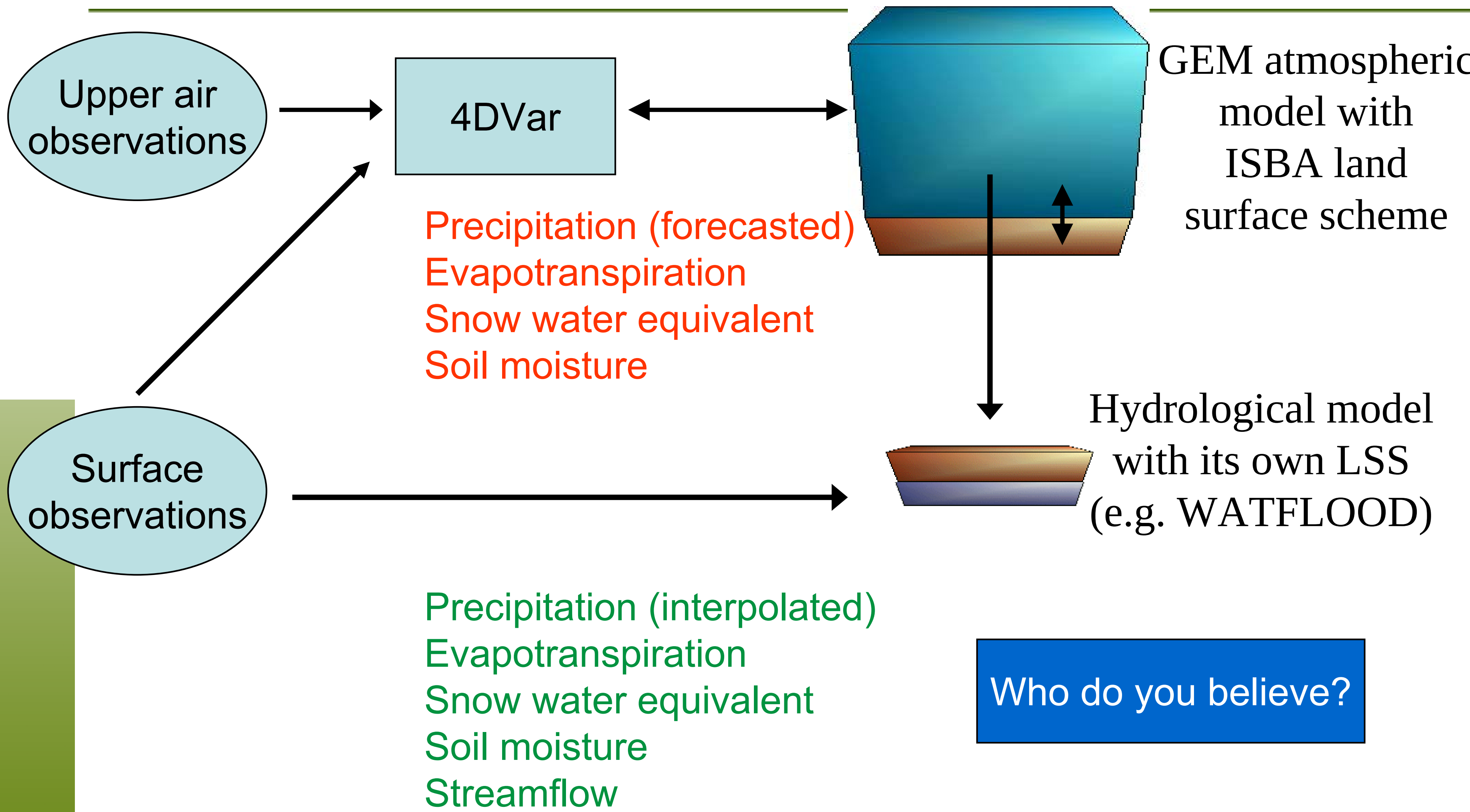


Can we couple atmospheric and hydrological models ?

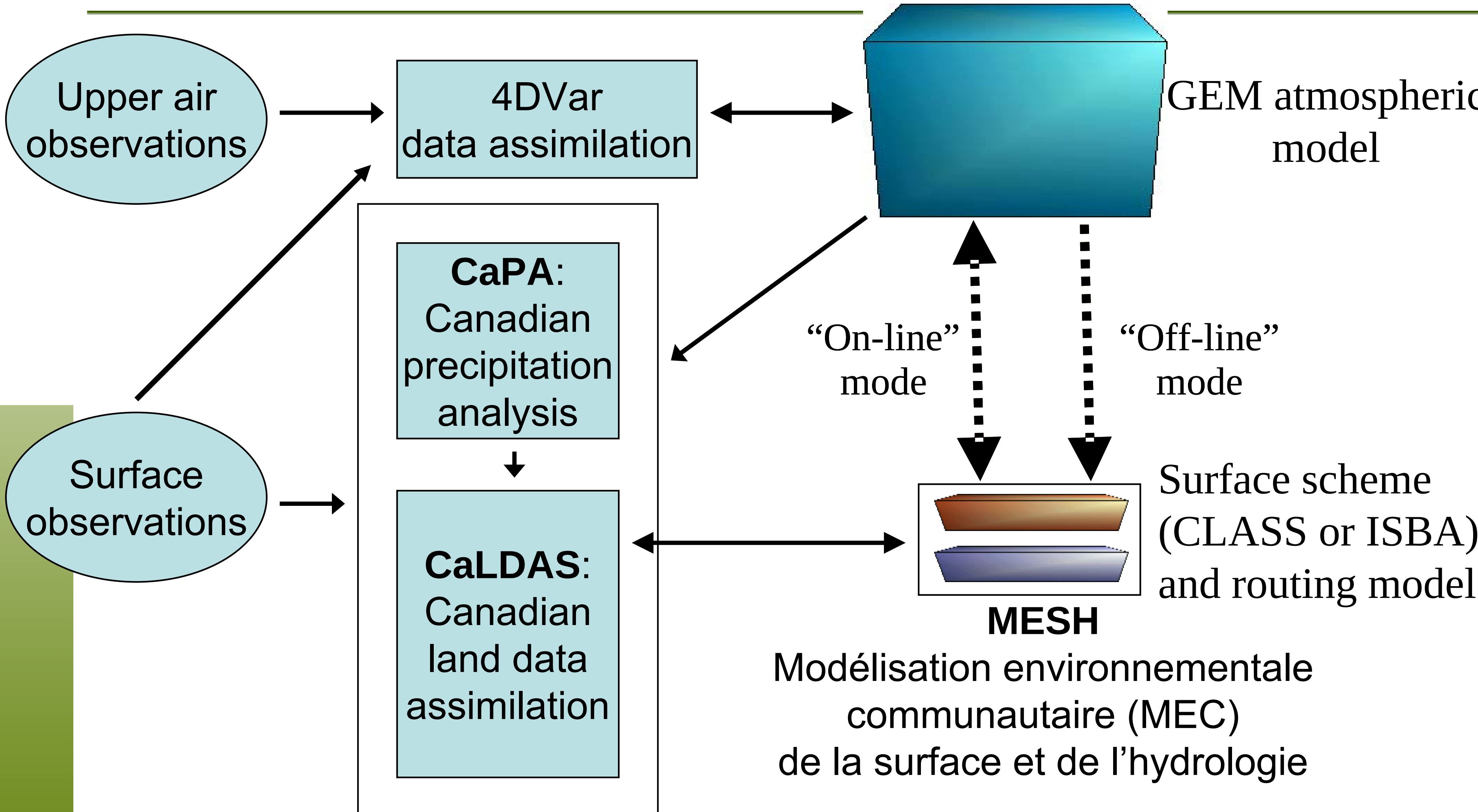
Numerical Weather Prediction Framework



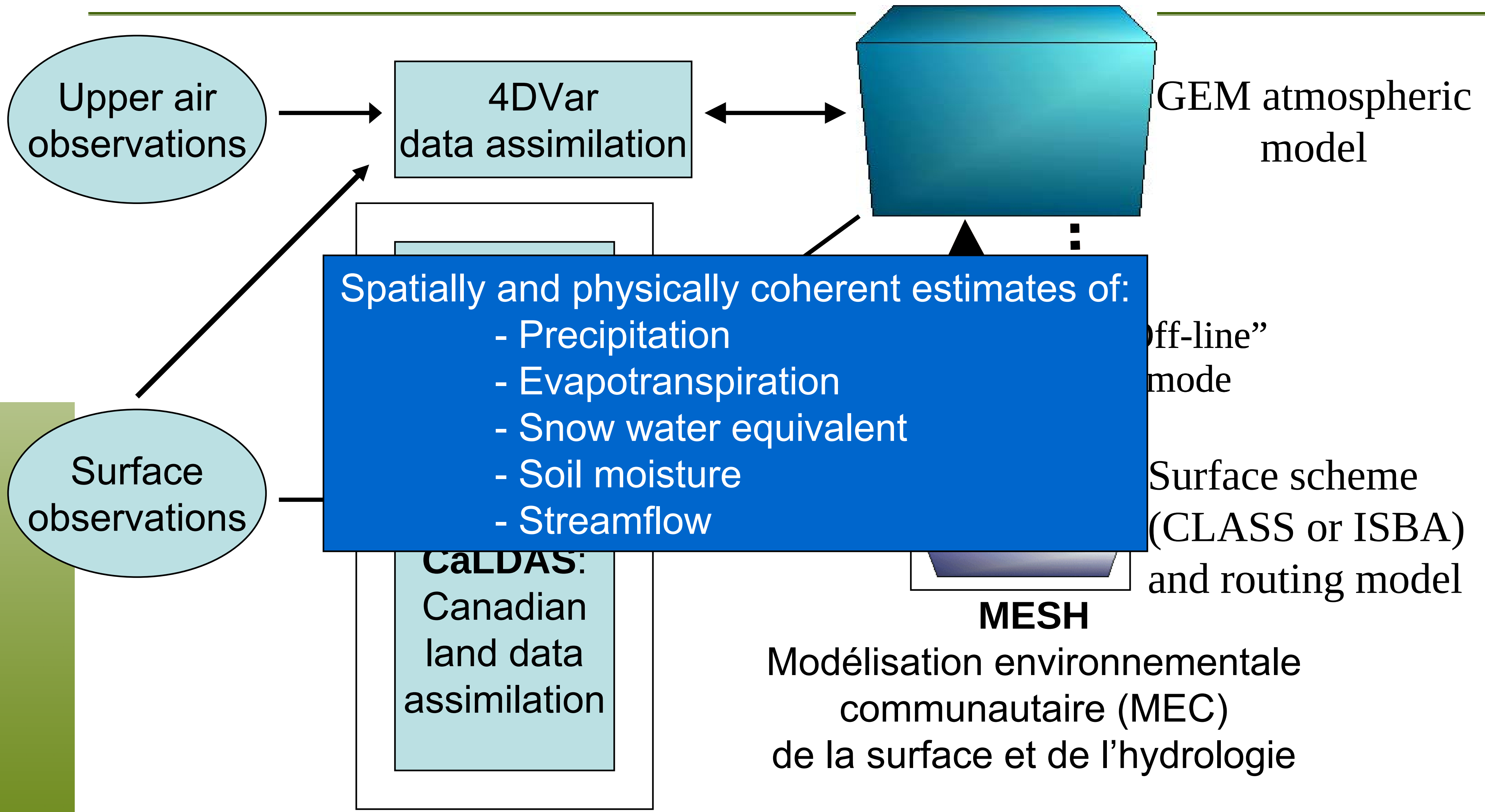
Hydrological Prediction Framework



Environmental Prediction Framework

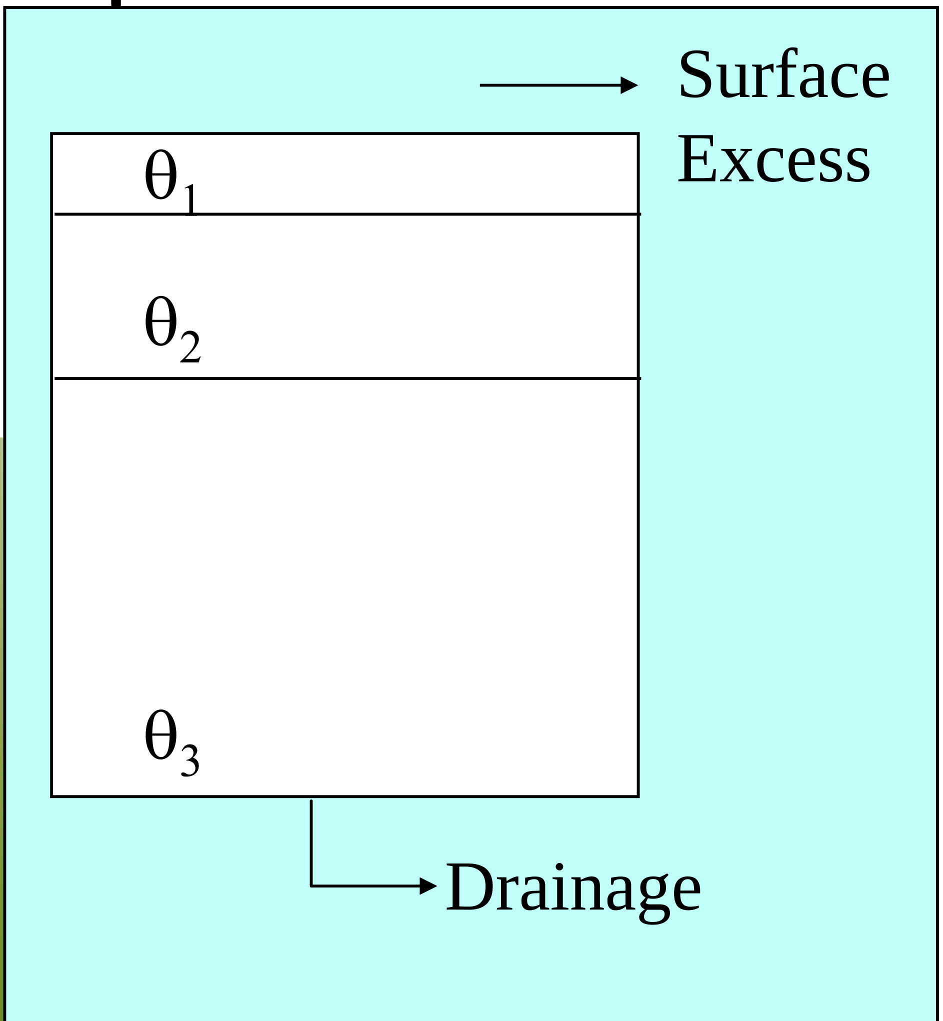


Environmental Prediction Framework

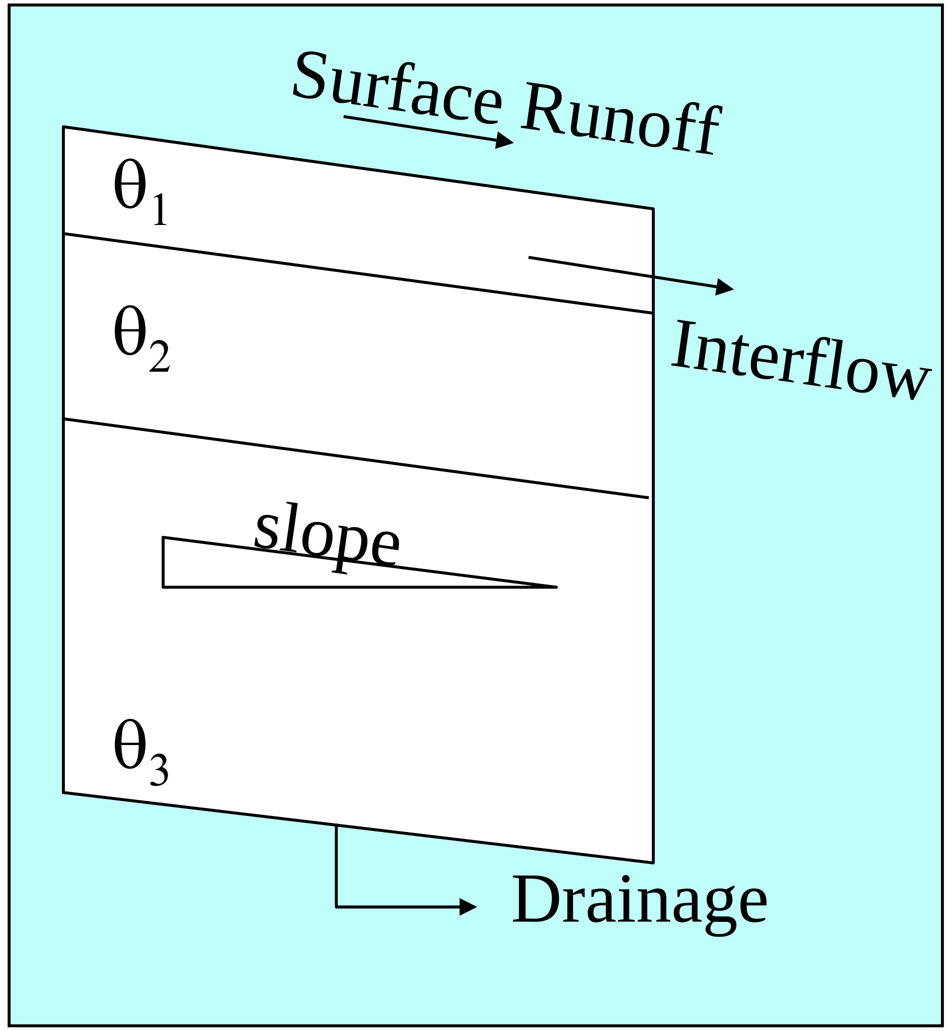


Improved Soil Water Balance

previous CLASS Model



CLASS 3.x/WATCLASS

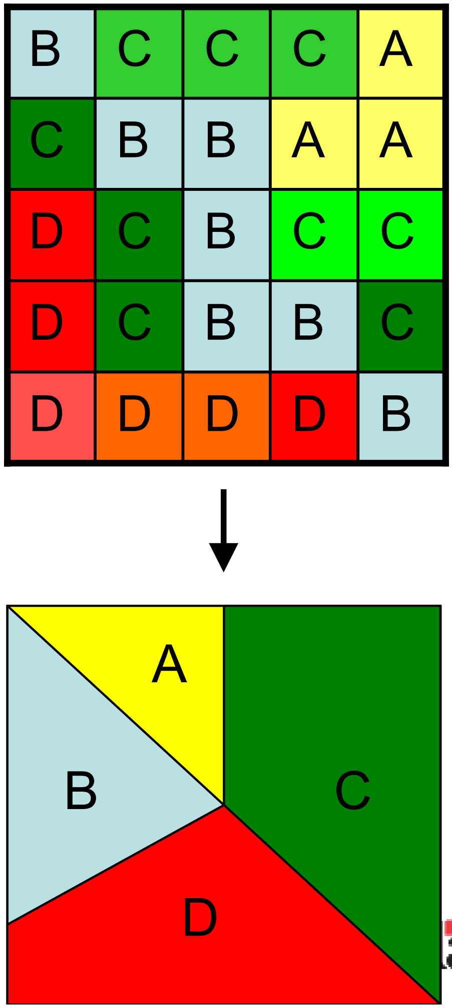


MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- Designed for a regular grid at a 1-15 km resolution
- Each grid divided into grouped response units (GRU or tiles) to deal with subgrid hetereogeneity

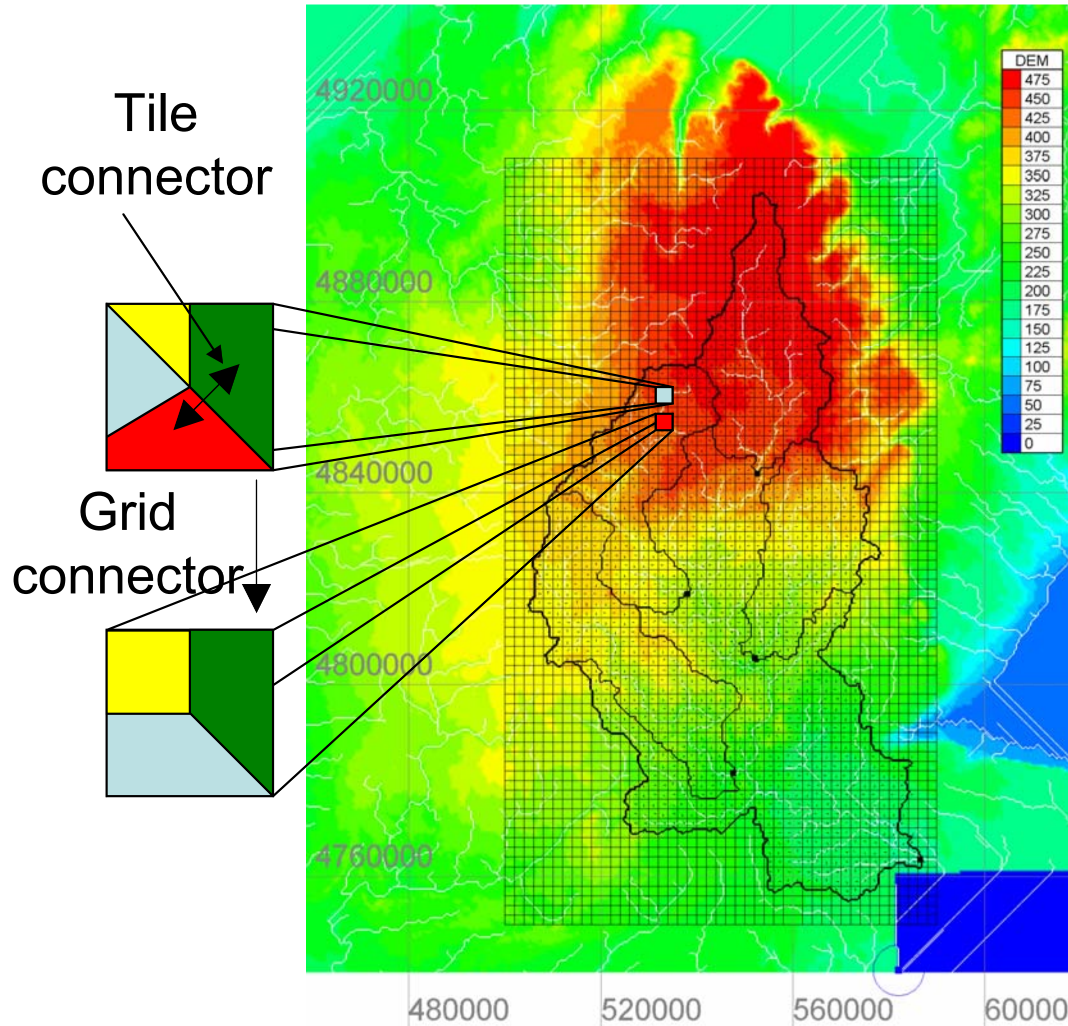
Sub-grid Hetereogeneity (land cover, soil type, slope, aspect, altitude)

A relatively small number of classes are kept, only the % of coverage for each class is kept



MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

- The tile connector (1D, scalable) redistributes mass and energy between tiles in a grid cell
  - e.g. snow drift
- The grid connector (2D) is responsible for routing runoff
  - can still be parallelized by grouping grid cells by subwatershed



Towards an integrated EP program

Streamflow is the integrator of the water and energy balance indictors at the basin outlet.

- Hydrometric data provides a "reality check" on any water cycle model indicators.
- Climate/synoptic data system provides data for assimilation and validation
- Data assimilation and analysis provides the best "interpolator" between observation points

- THE EC NWP (MEC/MESH) is our best solution to a consistent and rational approach to EP within the water cycle
- MESH can be run coupled or offline
- Public Domain – University partners are highly engaged
  - Look towards university sector for innovation

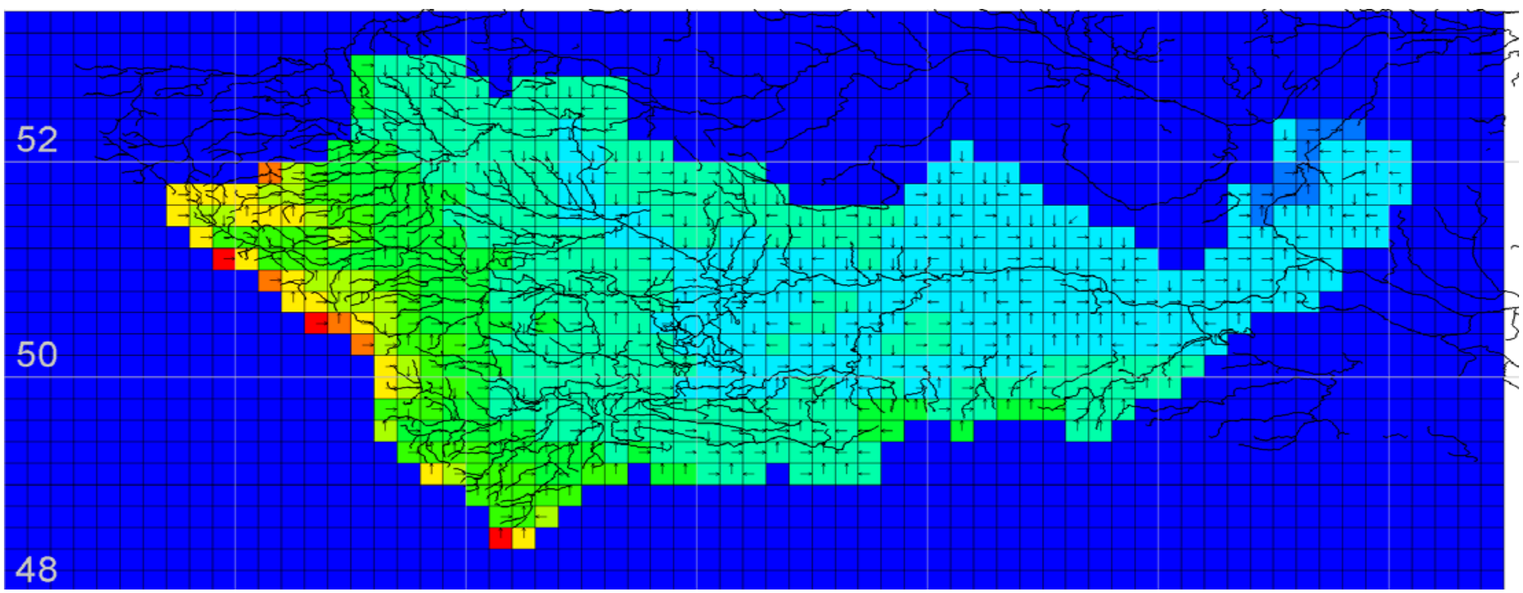
Testing the EP system (NAESI)
South Saskatchewan River Basin (SSRB)

Activities

- MESH development
- CaPA development
- CaLDAS development
- Assess the validity of MESH, CaPA and CaLDAS products
- WUAM development and verification
- Technology transfer

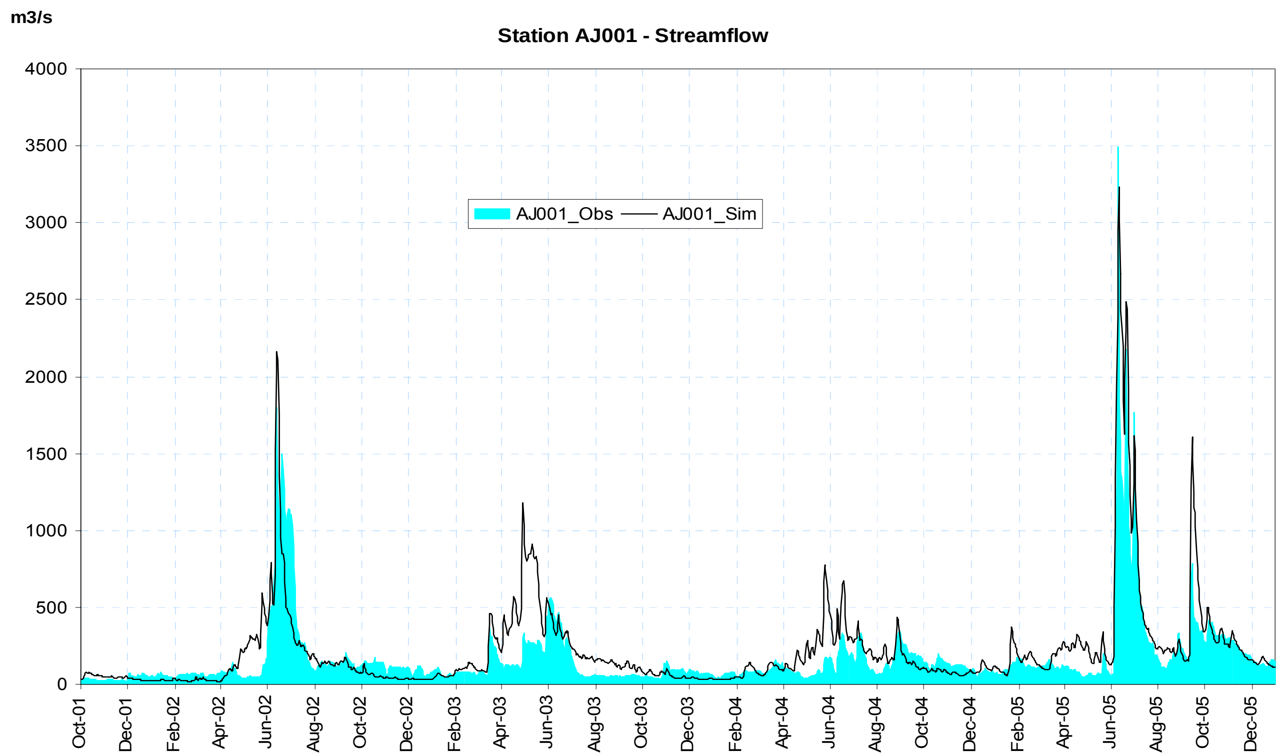
1. Hydrological modelling (MESH)

- Will use WATFLOOD model domain established in previous studies so as to be able to compare results
  - Horizontal resolution: 0.2 degrees
- Both CLASS 3.3 and ISBA land surface schemes will be tested
- Simulation period: 2001-2007



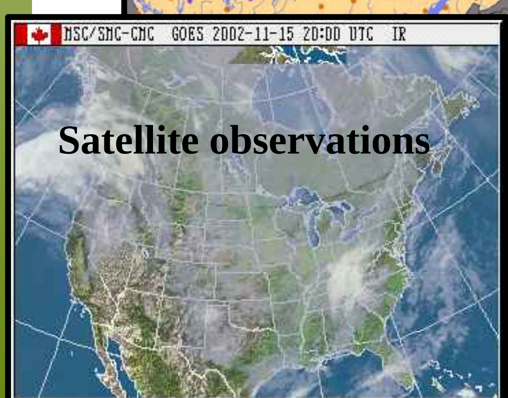
1. Hydrological modelling (MESH)

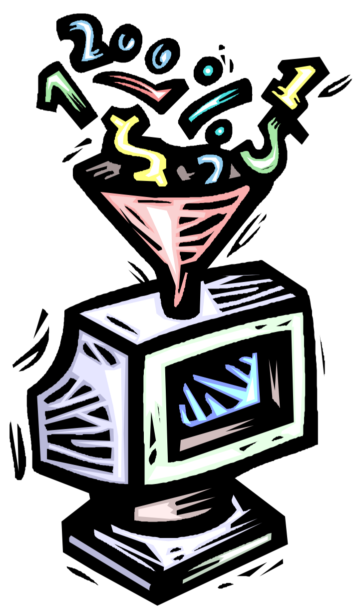
- South Sask at Medecine Hat (56K km²)
  - WATFLOOD simulation to which MESH will be compared

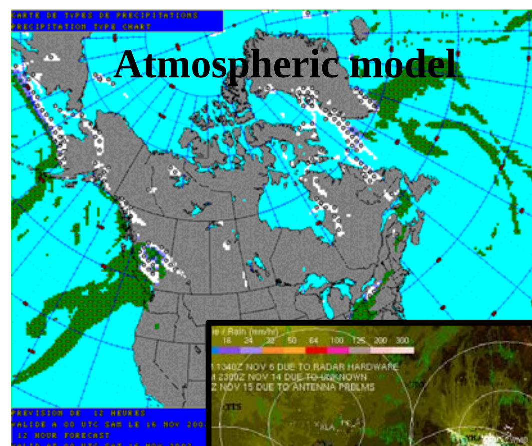


2. Precipitation analysis (CaPA)

- Combine different sources of information on precipitation into a single, near real-time analysis
  - Analysis of 6h accumulation of precipitation, covering all of North America on a 15km grid
  - Optimal interpolation technique to obtain our best estimate of precipitation

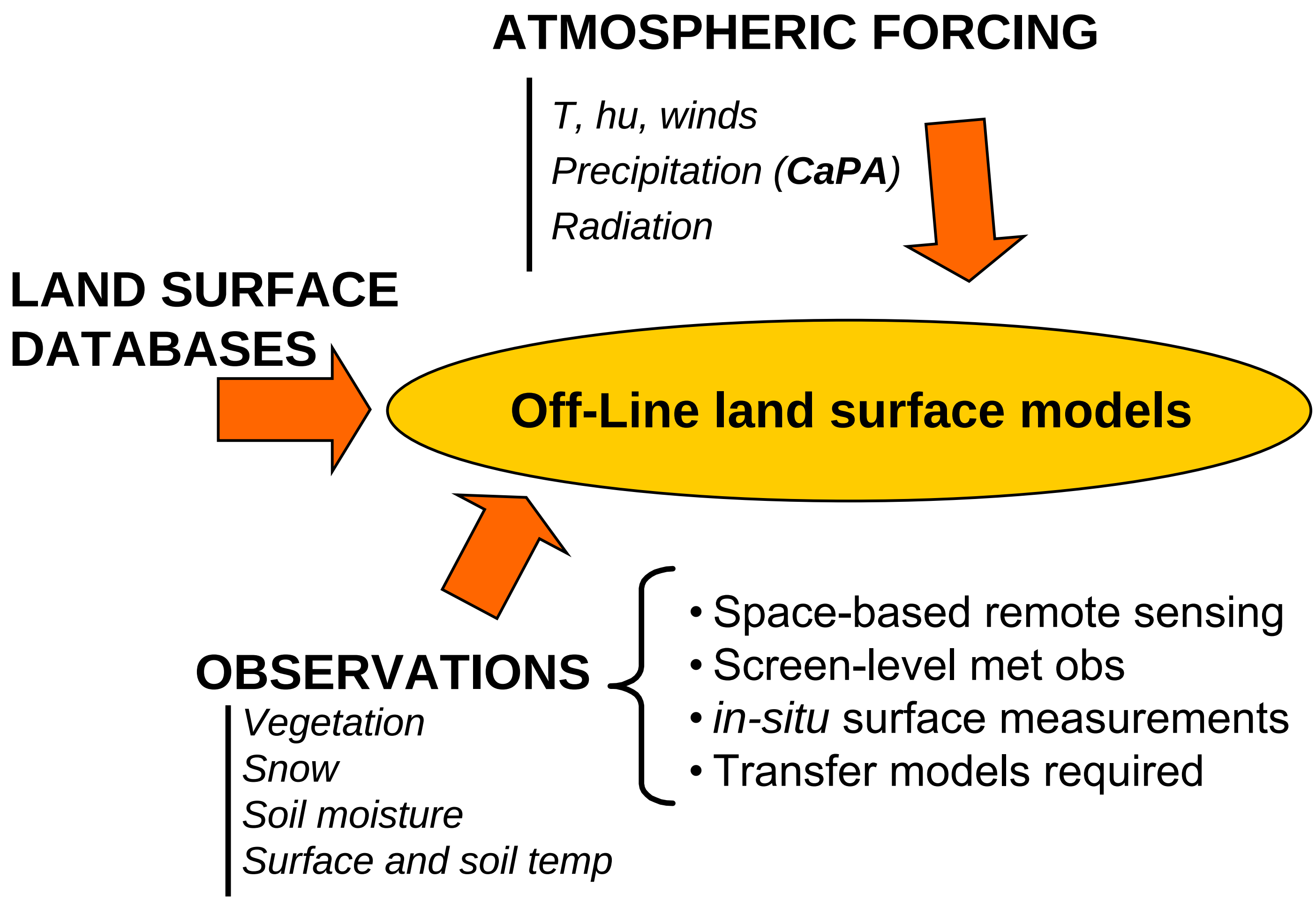






3. Land data assimilation (CaLDAS)

- Biases in energy and water storage can develop in coupled modeling systems due to incorrect representation of physical processes, atmospheric forcing, and surface characteristics.
- Land Data Assimilation Systems (LDAS) driven by observations and constrained by data assimilation have potential to more accurately depict land surface conditions



4. Assess the validity of the indicators

- Database of historic records (collated for 1998-2005)
  - Precipitation
  - Naturalized flows
  - Snow on the ground
- Data Collections for 2006 and 2007
  - Eddy covariance for ET flux assessment
  - TDR Soil Moisture network for soil moisture validation and assimilation
  - Discussions with AAFC Irrigation Development Centre (Outlook) for site selection.
  - Deep soil pressure transducer for integrated soil moisture changes

4. Assess the validity of the indicators

10x10km High Density Area (EC) in headwaters of Brightwater Creek:

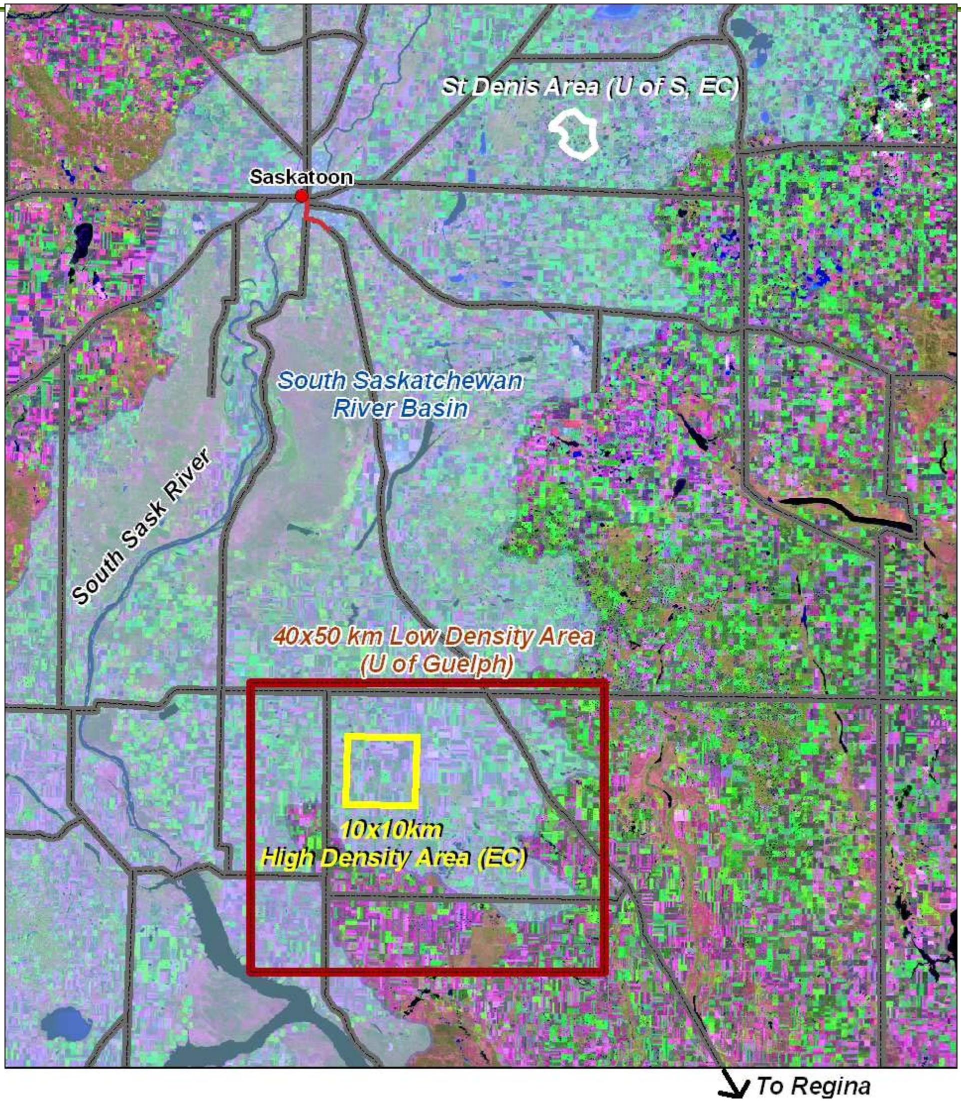
- 20-24 Soil moisture & precip stations
- 1 Energy Flux & Met tower
- 1 Potential deep well lysimeter (new or existing well)
- 13 Snow survey transects

40x50 km Low Density Area (U of Guelph):

- 14 Soil moisture & precip stations

St Denis Area (U of S, EC):

- 1 Energy Flux Tower
- Snow survey transects
- Soil moisture stations (numbers not decided)



Study Team

Management Leads: Gilbert Brunet and Fred Wrona

Investigators:

<u>EC</u>

Principal Investigators

Alain Pietroniro (AEIRD/HAL) and Pierre Pellerin (MRD)

Stephane Belair (MRD) - Data Assimilation

Vincent Fortin (MRD) – Precip Analysis and Hydrological Modelling

Dorothée Charpentier (MRD) – Data Assimilation

Isabelle Doré (MRD) – Hydrological Modelling

Bruce Davison (HAL) – Hydrological Modelling

Brenda Toth (HAL) – Hydrological Modelling

Matt Regier (HAL) – Network, Data Manager

Jessika Töyrä (NWRI) – Soil Moisture Network and Remote Sensing

Raoul Granger (NWRI) – Evaporative Fluxes

Garth van der Kamp (NWRI) – Ground Water

Diana Verseghy (CRD) – CLASS model support

Dave Patrick (HAL) – CaPA and Modelling

Atef . Kassem (WPCD) – Water Use and analysis

T. Hamory (WPCD) – Water Use and analysis

Ivan Vouk (WPCD) – Water Use and analysis

David Burke(WPCD) – Water Use and analysis

Jean-Guy Zakrevsky (WSC) – Client Liaison

Michel Jean (CMC) – Client Liaison

Marco Carrera (CMC) – Precip Analysis and Data Assimilation

In collaboration with:

<u>Environment Canada</u>

Anne Walker (CRD) – Remote Sensing

Yves Durocher (MSC) – EC Met station Contact

<u>Agriculture Canada</u>

Jacques Millette – Outlook Irrigation Centre contact

Gordon Bell, PFRA – Saskatoon

Harvey Hill, PFRA - Saskatoon

<u>University of Saskatchewan</u>

John Pomeroy (DRI program lead)

Lawrence Martz – socio-economics

<u>University of Guelph</u>

Aaron Berg – Soil Moisture Network

<u>Alberta Agriculture Food and Rural Development</u>

Ralph Wright – Provincial Met Station Contact

Opportunities for CGEO in Water Cycle

- EC Environmental Prediction Program is incorporated into our operational numerical modelling system
  - 24/7 operation – super computer infrastrcuture
  - Earth systems science approach
  - Sophisticated 4 – D var assimilation
    - Provides best interpolation
  - Results only as good as the data that good into the system and models
  - We need continuous feedback between modeling and monitoring
- Community-based modelling approach
  - Encourages collaboration and innovation
- Stick to what we are good at and do the hard stuff.
  - Collaboration within the federal house
    - AAFC- EC-CCRS …….
    - Collaboration with universities centres of expertise
- Integrated programs don't require development of generalists. They require teams of specialists.