Regional modelling with a simple land surface model: the strengths, weaknesses and a novel implementation of the Variable Infiltration Capacity (VIC) model

Shervan Gharari, Saman Razavi, Jefferson Wong, Alain Pietroniro, Howard Wheater

Integrated Modelling Program for Canada
Global Water Futures
GLOBAL WATER FUTURES
SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE
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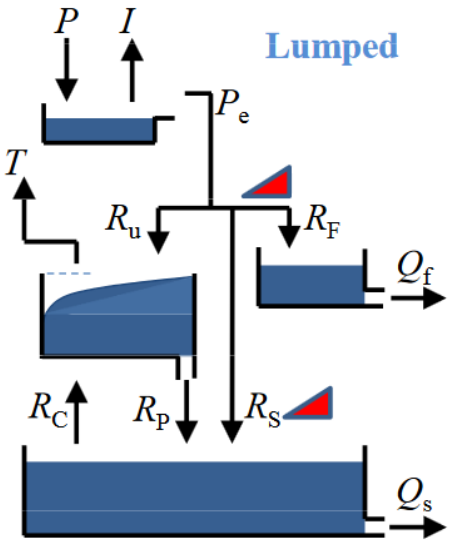
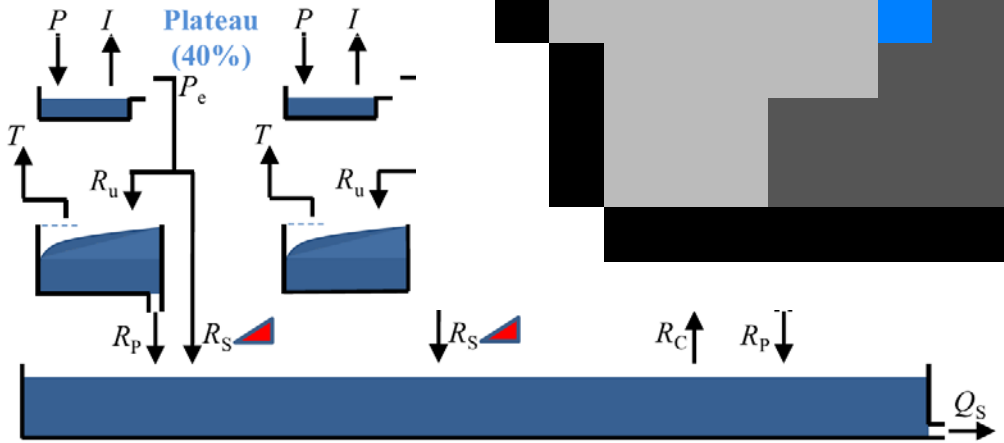
A brief background about myself

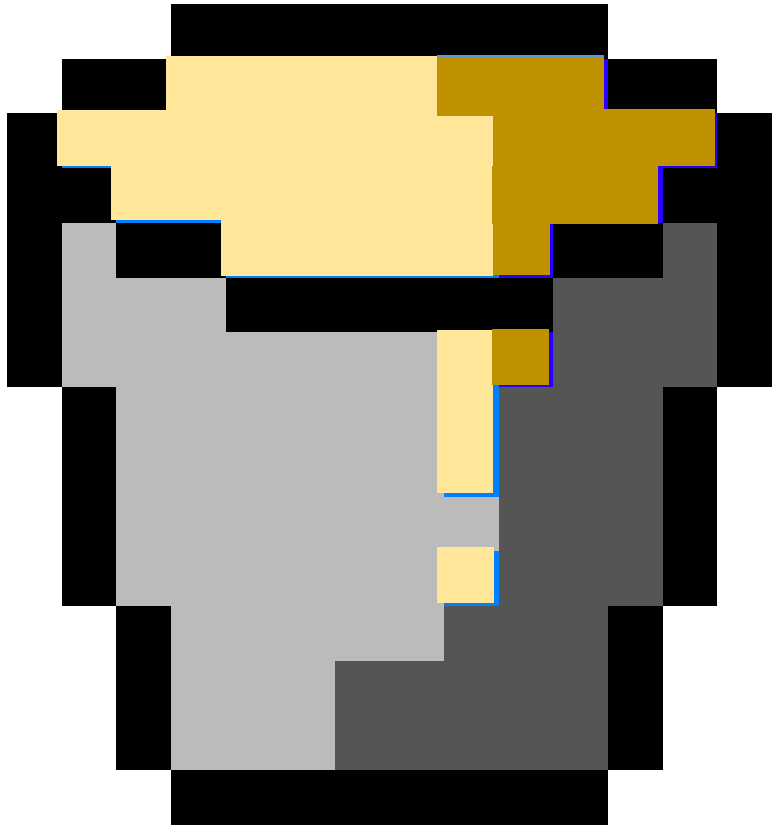
PhD Life

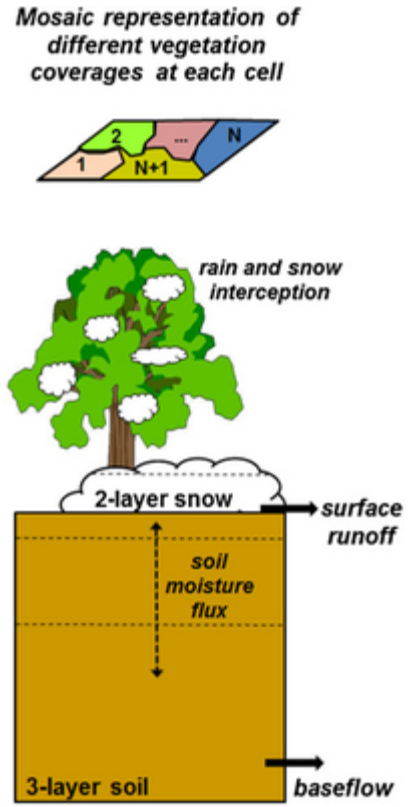
PDF Life



TOPO-FLEX
Gharari et al., 2014

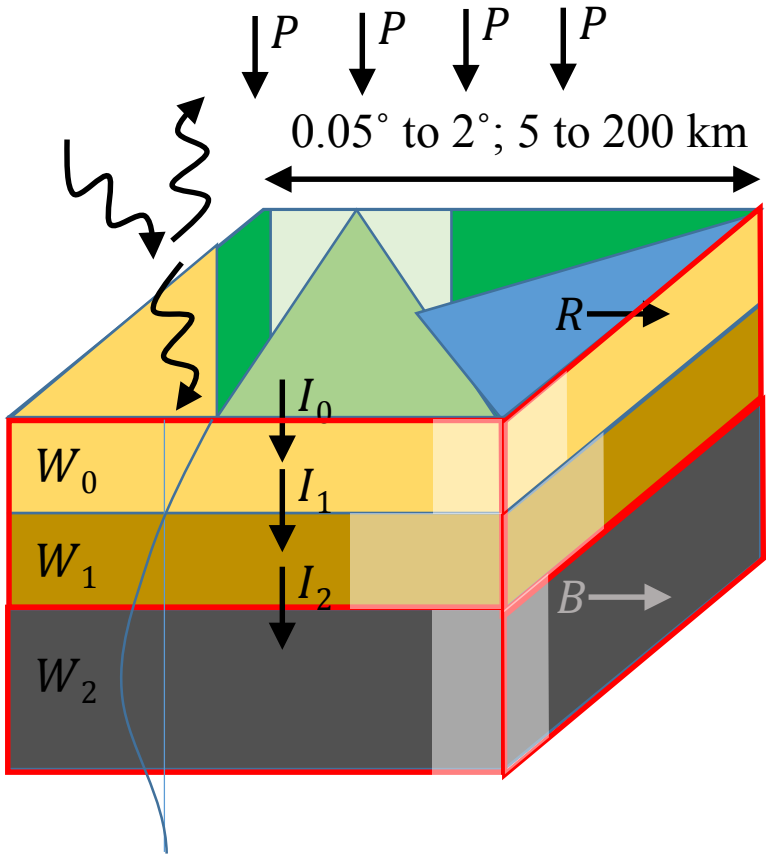


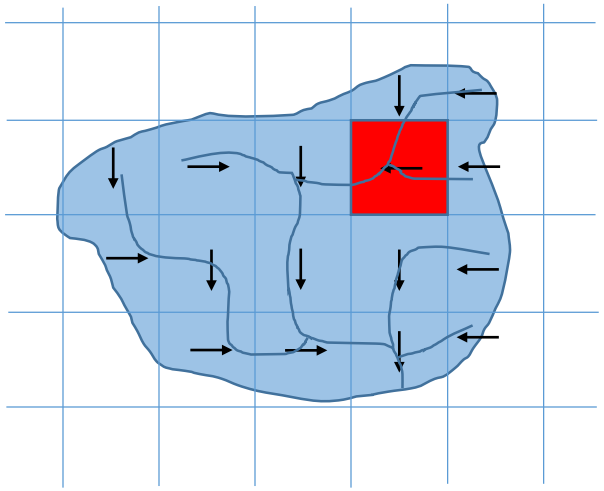




VIC
Mendoza et al., 2015

VIC in a glimpse





VIC stands for Variable Infiltration Capacity; developed as a simple land surface model (Liang et al., 1994).

VIC is a meso- to large- scale model at grid scale.

The soil characteristics are considered to be homogeneous for every soil layer in a gird and can vary from one grid to another.

VIC accounts for various land covers and lakes within a grid.

Infiltration capacity varies based on a distribution of saturated areas define by *b* as infiltration shape parameter.

$I_0 = f(W_0+W_1)$; $R = P - I_0$;

Base flow is calculated based on storage of the lowest soil layer as a nonlinear reservoir.

$B = f(W_2)$

Water flow between the layers are calculated by an approximation of Richards equation.

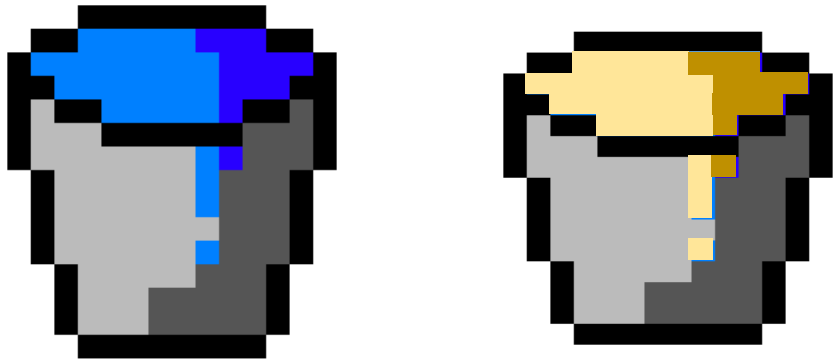
VIC is able to calculate energy fluxes for soil profile and lake (1-D lake model).

VIC is able to account for frozen soil and its impact on infiltration and transpiration.

The routing model is consist of a unit hydrograph at a grid scale and linearized Saint-Venant equation based on velocity and diffusivity.

What made VIC, VIC?

- It is simple (easy to understand for bucket eeers like me!).
- It uses combinations of conceptual and physical representations (not too physical, not too conceptual).
- It has a powerful infiltration formulation (HBV-type). It fits everything!!
- Earlier versions (before V.5) uses daily time series as input.

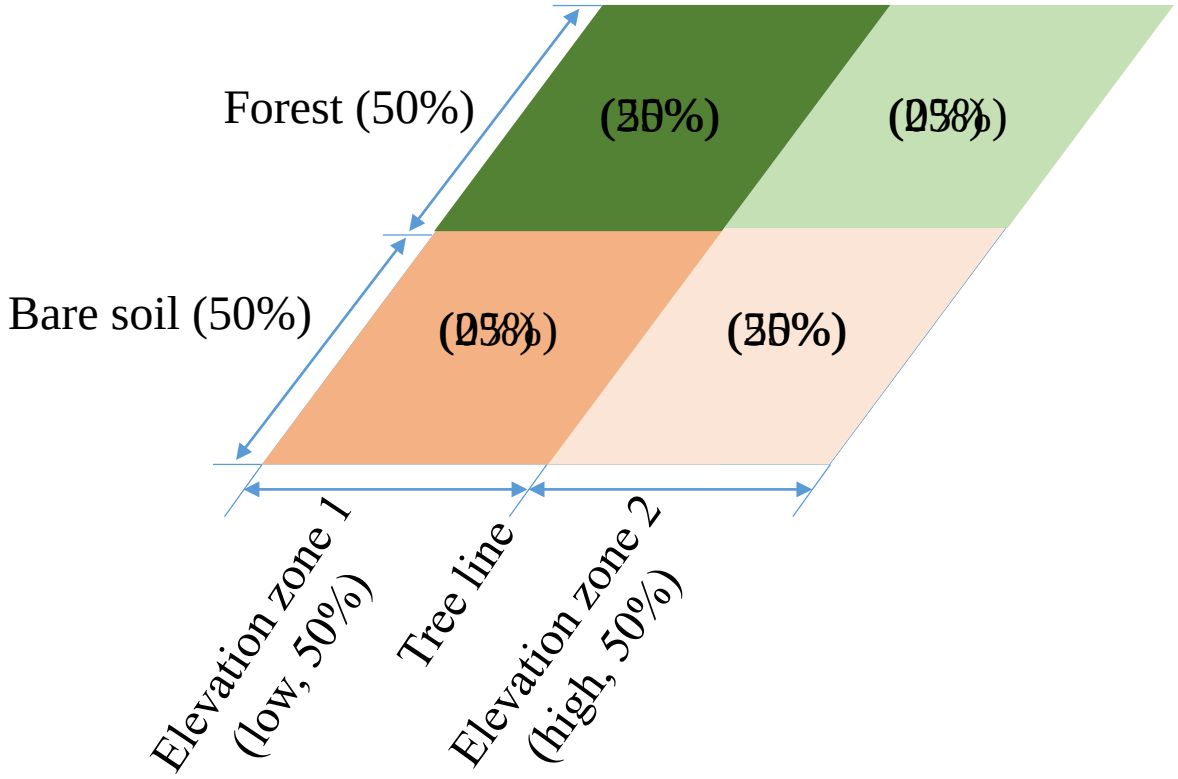


GWF VIC-related activities – (1) Assessment/improvement

We have reviewed +50 articles related to VIC

- True model validation/evaluation is rare.
- Not very good performance in accordance with *in situ* observation
- Routing which includes reservoir operation is usually not reported (except one paper; which is not mentioned how it was implemented).
- Regionalization of the conceptual parameters is not well explored (only one recent paper to our knowledge).
- Model parameters uncertainty and sensitivity is not well explored (only one paper to our knowledge).
- Assumptions on within grid cell variabilities might be unrealistic and computationally inefficient.

GWF VIC-related activities – (2) Model set up



GWF VIC-related activities – (2) Model set up (VIC-GRU)

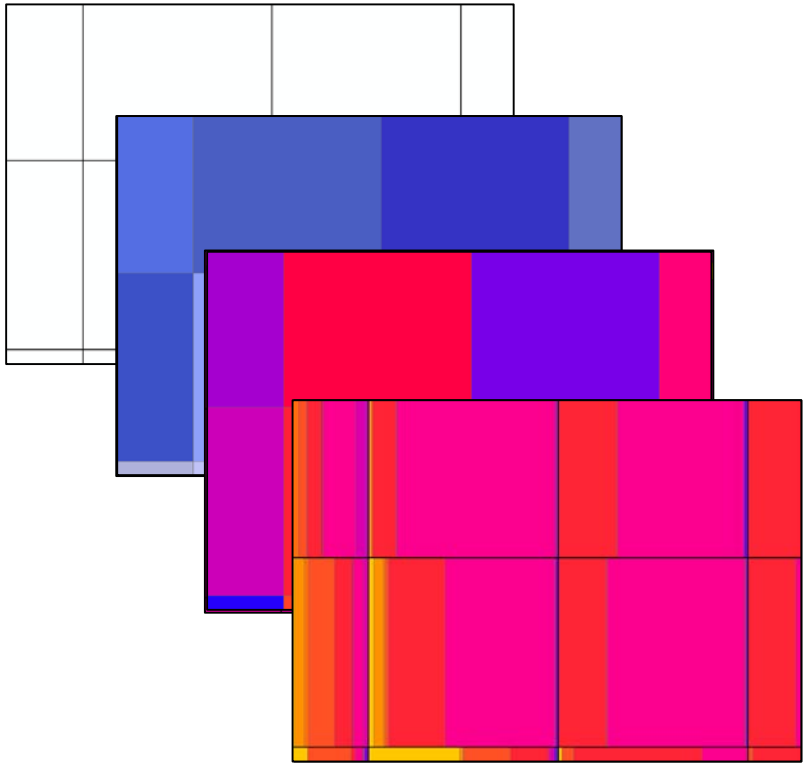
Traditional VIC implementation

A cell size should be decided

Forcing should be aggregated

Soil parameter should be aggregated

Percentage of each land cover is only used for every grid. Spatial extent is lost.



VIC-GRU implementation

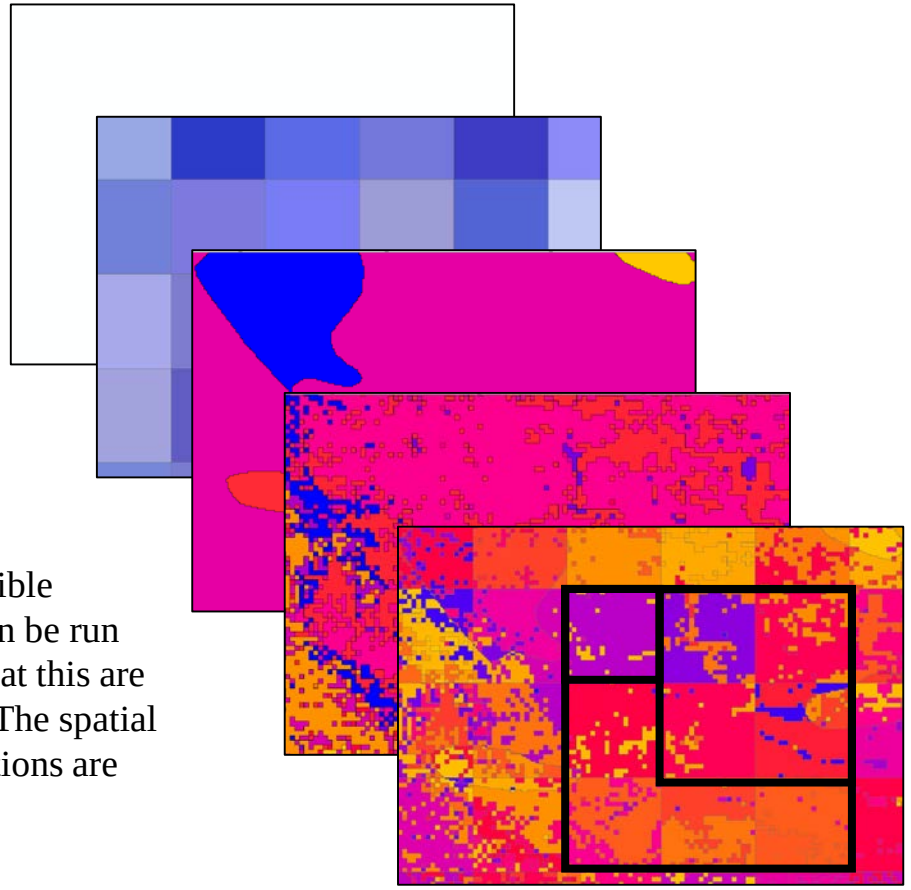
No cell size is needed

Forcing remains the original resolution

Soil parameter remains the original resolution

Land cover extent are preserved.

This is the highest possible resolution the model can be run for, resolution higher that this are computational burden. The spatial extent of model simulations are preserved.



GWF VIC-related activities – (2) Model set up (VIC-GRU)

Advantages of VIC-GRU:

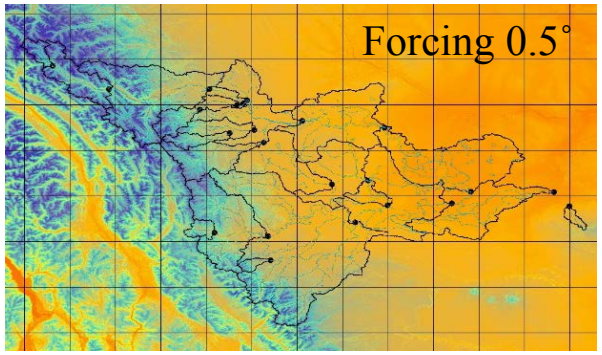
- It is the most computationally efficient model set up, any set up with more number of elements is an unnecessary computational burden.
- The effects of land cover, soil type, elevation zones can be controlled separately and relative constraints can be imposed based on them.
- It simplifies the VIC input files.
- It can help to account for various configurations, for example, forcing can be amended based on the aspect of every GRUs.

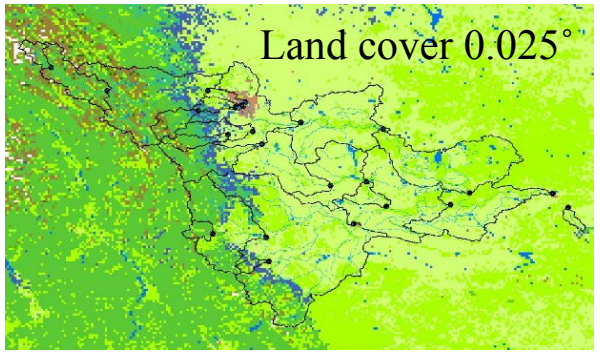
GWF VIC-related activities – (2) Model set up (VIC-GRU)

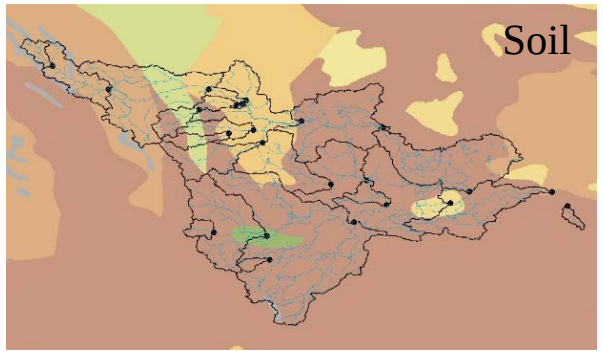
Advantages of VIC-GRU:

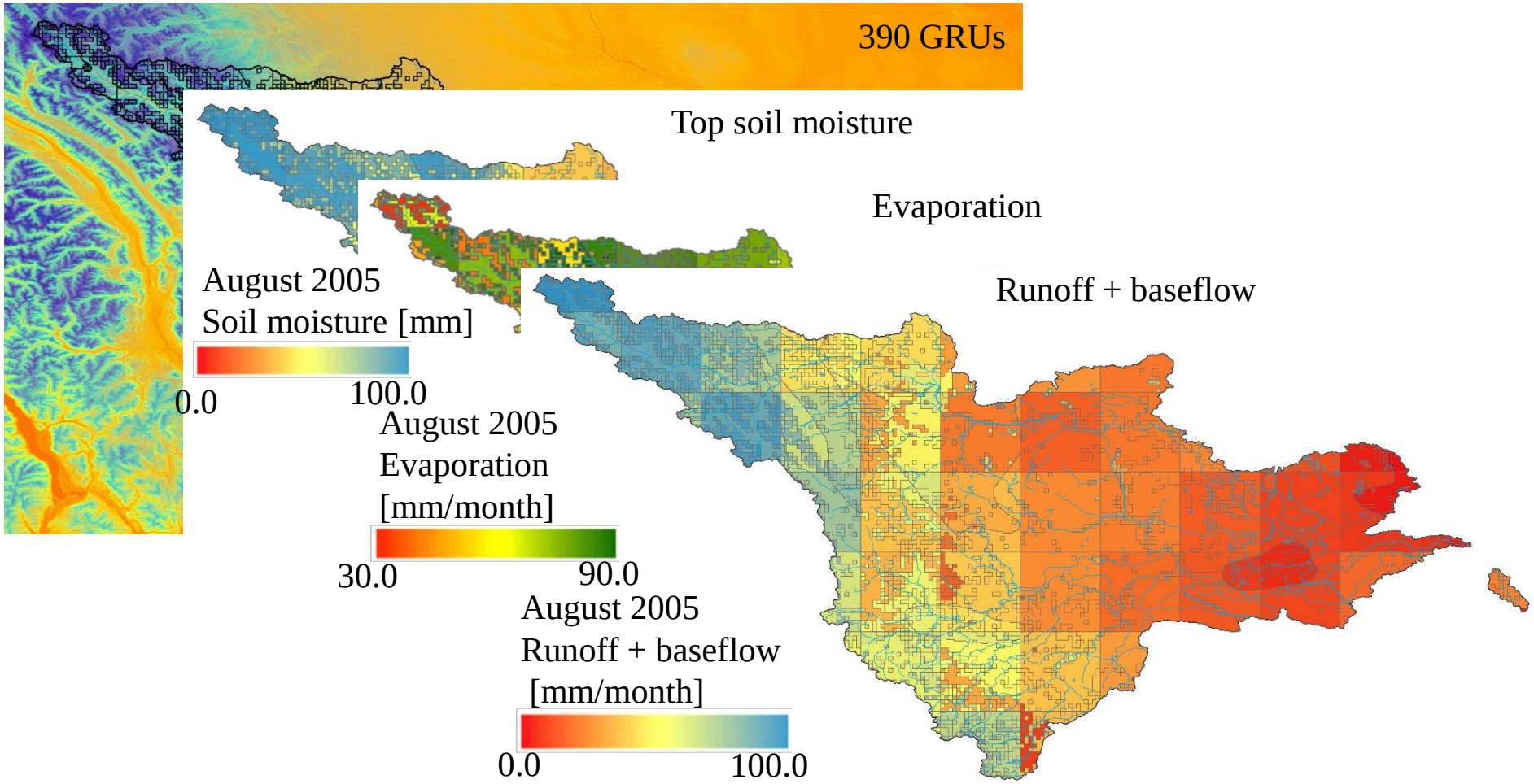
- It makes the model comparison easier with GRU-oriented models such as MESH or SUMMA.
- The change of the land cover over time can be directly applied to the proportions of every GRUs.

GWF VIC-related activities – (2) Model set up (VIC-GRU)

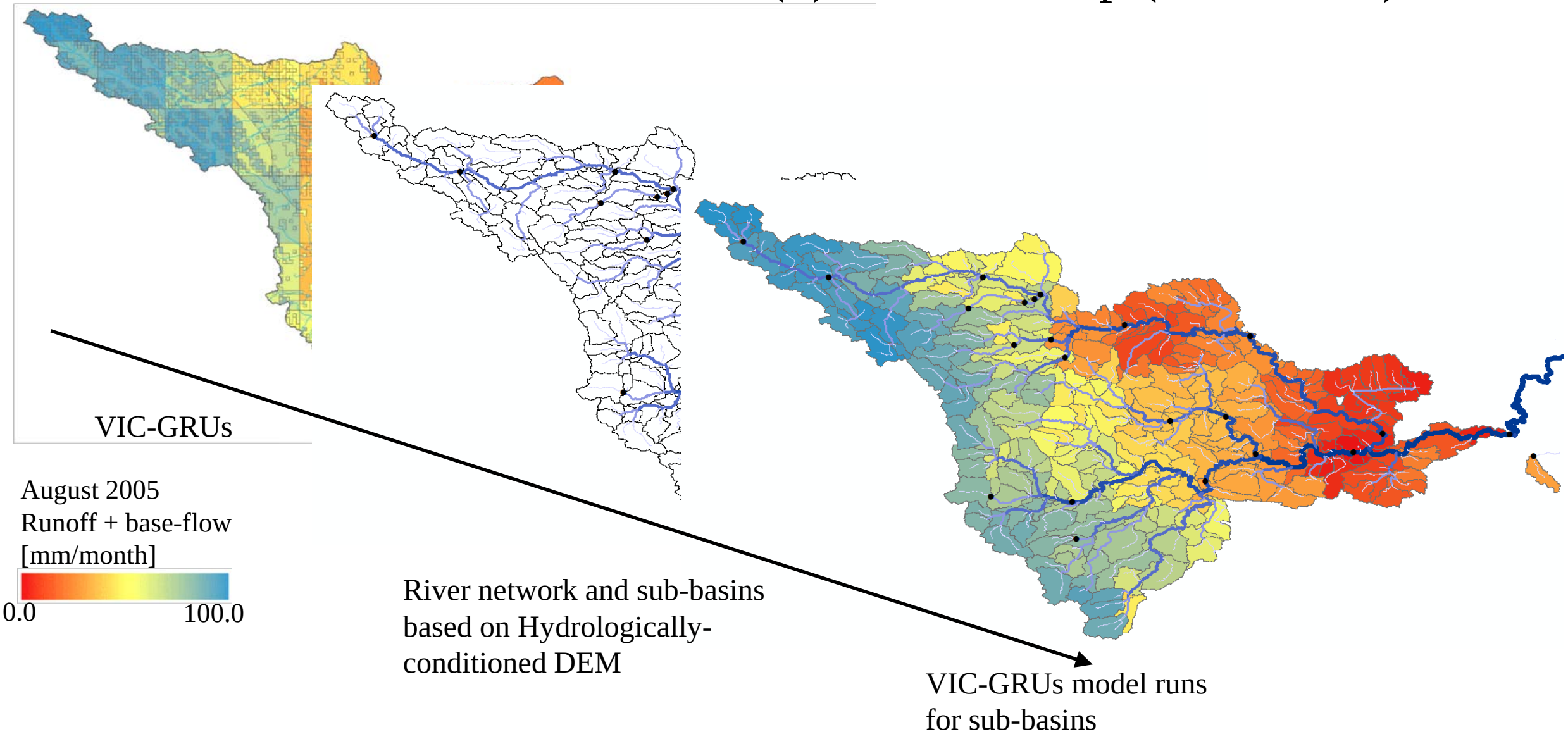






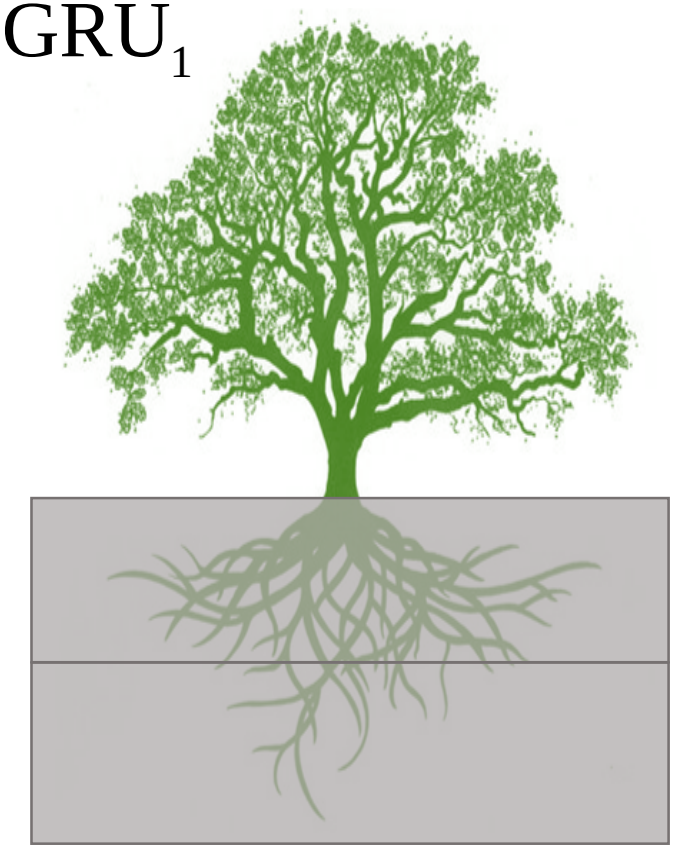


GWF VIC-related activities – (2) Model set up (VIC-GRU)



GWF VIC-related activities – (3) Optimization, Sensitivity and Uncertainty Analysis

GRU_1



Parameter constraints:

$$root_{GRU_1,layer_1}[\%] > root_{GRU_2,layer_1}[\%]$$

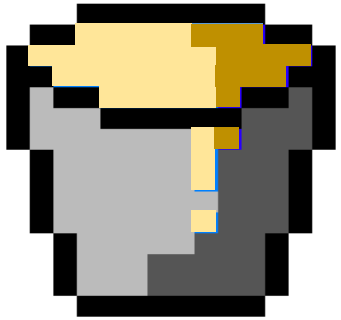
$$depth_{GRU_2,layer_2}[m] > depth_{GRU_1,layer_2}[m]$$

$$depth_{GRU_1,layer_1}[m] = depth_{GRU_2,layer_1}[m]$$

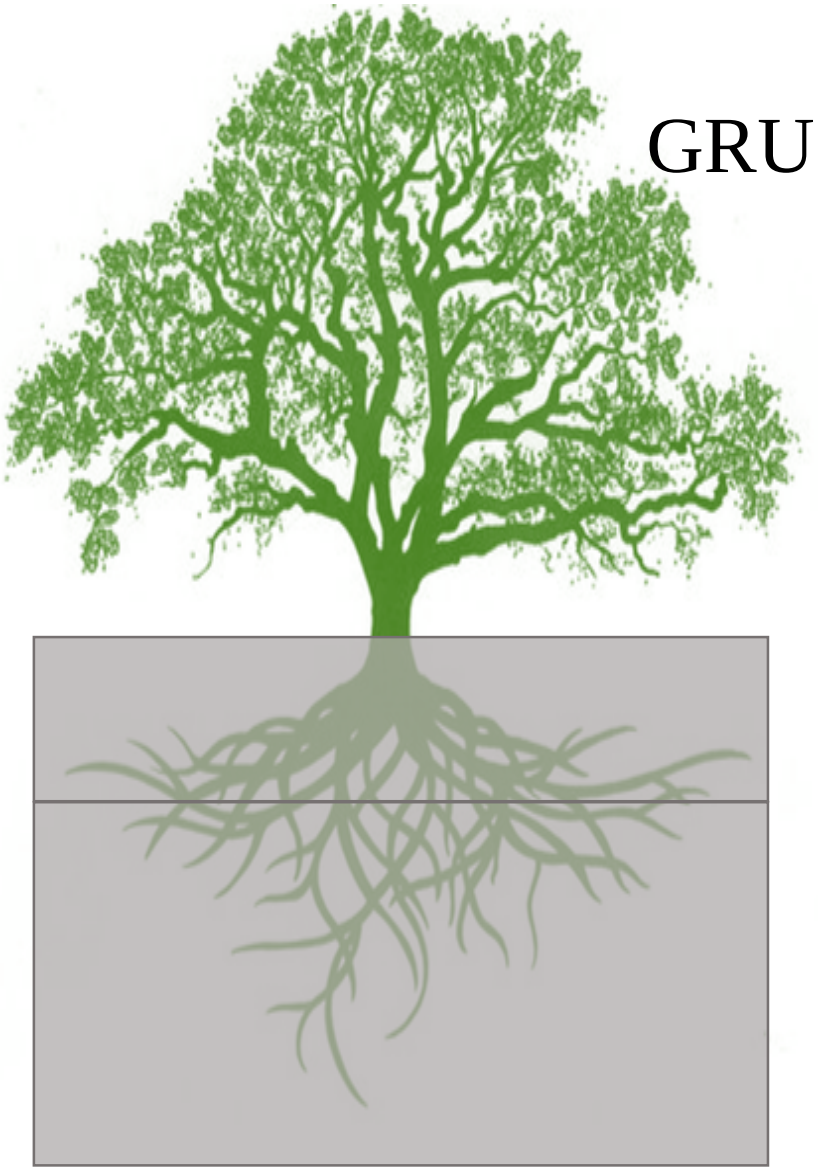
Process constraints:

$$ET_{GRU_2}[mm/yr] > ET_{GRU_1}[mm/yr]$$

$$R_{GRU_1}[mm/\ yr] > R_{GRU_2}[mm/\ yr]$$

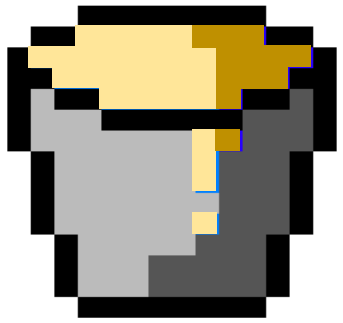


GRU_2



GWF VIC-related activities – (3) Optimization, Sensitivity and Uncertainty Analysis

Soil parameters		
Conceptual soil parameters	Infilt	Variable infiltration curve parameter (b_{infilt})
	Dsmax	Fraction of Dsmax where non-linear base flow begins
	Ds	Maximum velocity of base flow
	Ws	Fraction of maximum soil moisture where non-linear base flow occurs
	c	Exponent used in baseflow curve, normally set to 2
	depth	Thickness of each soil moisture layer
Physical soil parameters	Expt	
	Ksat	
	Phi_s	
	bubble	Bubbling pressure
	quartz	Fraction of quartz
	Bulk_density	
	Soil_density	
	Wcr_FRACT	Fraction of soil moisture content at critical point
	Wpwp_FRACT	Fraction of soil moisture at wilting point
	Resid moist	



GWF VIC-related activities – (4) Scenarios of Change

Scenarios of change should be prepared for to the VIC model.

The VIC model doesn’t have any formulation or parameterization which can guarantee the long term trend outside of yearly cycles.

The VIC model is the consumer of future scenarios, not the producer…

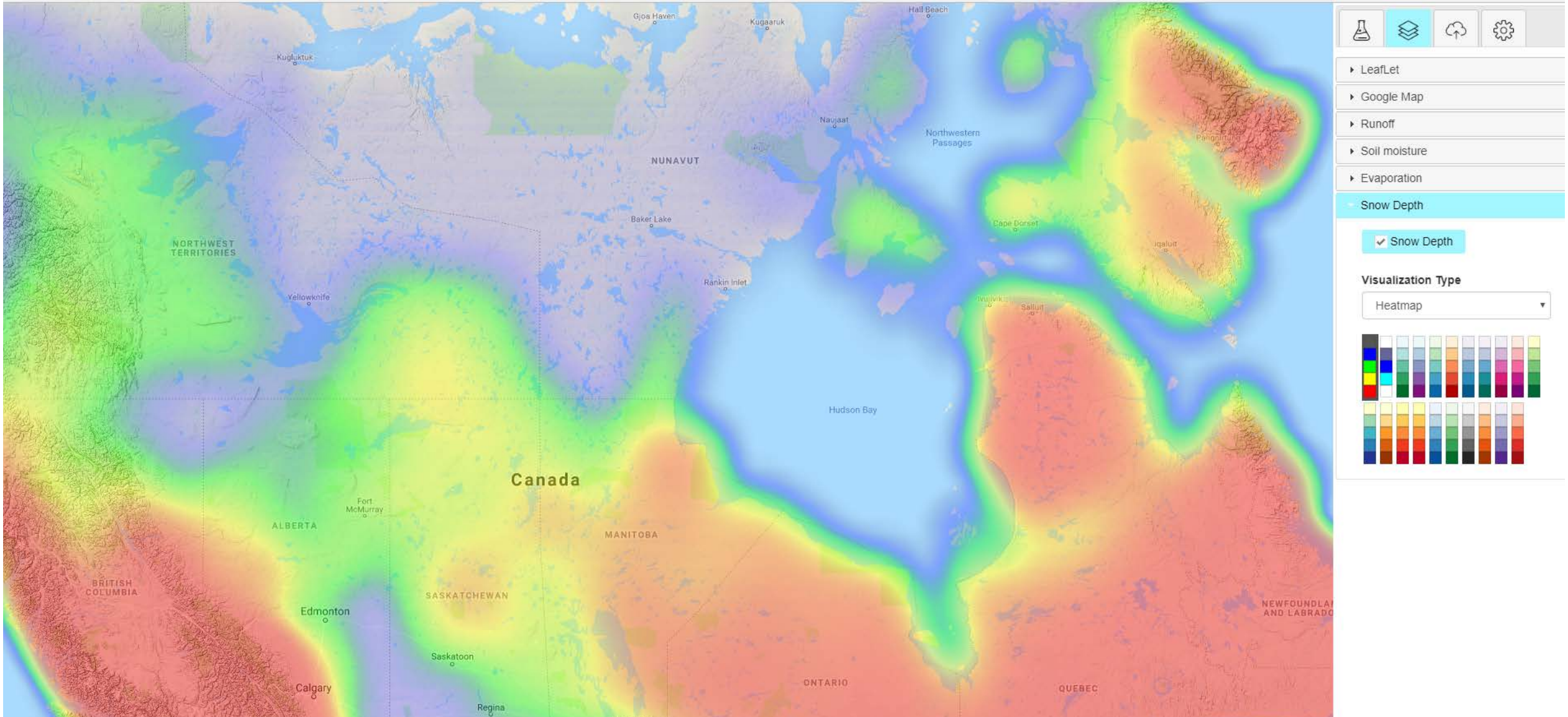
GWF VIC-related activities – (5) Communication

Name	Temporal resolution	Temporal extent	Spatial resolution	Spatial extent	Variables	Format	Local access	Web Access	Additional information and notes
GEM (RDPS, HRDPS)	1-hour	2001/10-present	0.22 deg (~24 km): 2001/10-2004/05/17 0.1375 deg (~15 km): 2004/05/18-2012/10/02 10 km (likely 0.09 deg): 2012/10/03-present 0.0225 degree (~2.5 km): 2012/10/03-present	North America: 2016/09/08-present Canada, Mexico, conterminous US: 2010/11-present Canada, continental US: 2001/10-present	Precipitation, temperature, pressure, specific humidity, wind speed, downward SWR, downward LWR	fst (with rmnlib), ASCII, GRIB 2 (convertable to NetCDF)	?? (most probably GLOBAL WATER)	ECCC (Daniel Princz)	Wind, temperature and specific humidity are reported at the height of 40 m; wind at 10 m and temperature, specific humidity at 2 m available from 2010/01-present. Data from 00,12h forecasts available from 2001/10; addition of 06,18h forecasts from 2010/01 More info here: http://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/table_of_contents_e.html
CaPA (RDPA)	6-hour Daily	2002-present	10 km	Canada, Mexico, conterminous US: 2002/01-present	Precipitation	fst (with rmnlib), ASCII, GRIB 2 (convertable to NetCDF)	?? (most probably GLOBAL WATER)	ECCC (Daniel Princz)	Blends observed data where available into GEM precipitation field; includes radar as of 2014/11/18.
WFDEI	3-hour Daily				Rainfall-CRU, Snowfall-CRU, Rainfall-GPCC,		?? (most probably GLOBAL		
WFD	3-hour Dily								
Princeton V.1 and V.2	3-hour Daily Monthly								
NARR	3-hour Daily Monthly								
ANUSPLIN	Daily Monthly								
CANGRD	Monthly seasonal								

Name	Spatial Resolution or Scale	Spatial extent	Format	Access	Date of Issue	Additional information and notes
Soil landscape of Canada, V2.2	1:1,000,000	Canada	shapefile	jade:\KuljeetK\soil data\Canada SLC 2.2 Soil Data	1996	there are some discripancies in data
Soil landscape of Canada, V3.2	1:1,000,000	Agricultural regions of Canada	shapefile	jade:\KuljeetK\Soil Data\Canada SLC 3.2 Soil Data	March 2011	there are a lot of gaps in data and infomration is not available.
Unified North American Soil Data (UNASM soil data)	250 m	Canada, USA	Raster	jade:\KuljeetK\Soil Data\UNASM Soil Data	May 2013	
STATSGO2 USA	1:250,000 in US, HI, PR, VI and 1:1,000,000 in AK	USA	USA	jade:\KuljeetK\Soil Data\USA STATSGO2 Soil Data	30 December 2015	
Harmonized Workd	0.00833 degree	Global	Global	http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-	7 March 2012	this is based on FAO data in raster format. The raster refere to an ID

GWF VIC-related activities – (5) Communication

http://gwf-demo.usask.ca/



Questions and discussions

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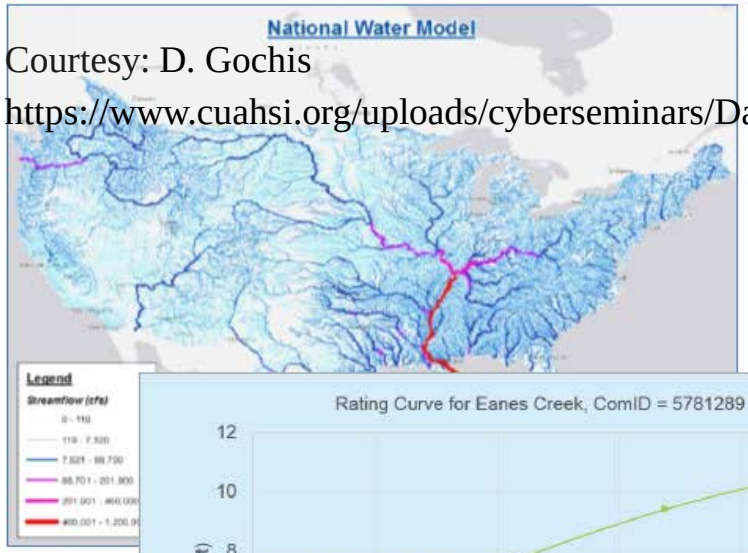
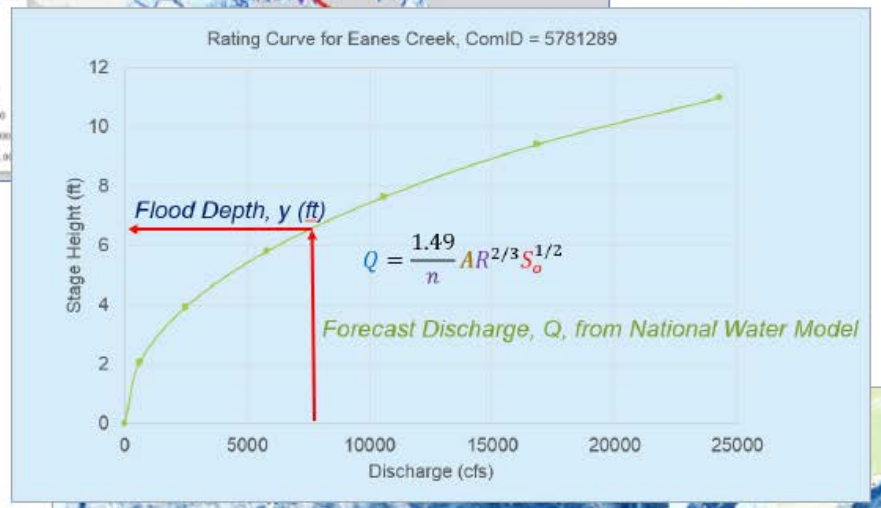
Flood Inundation Mapping: HAND Method

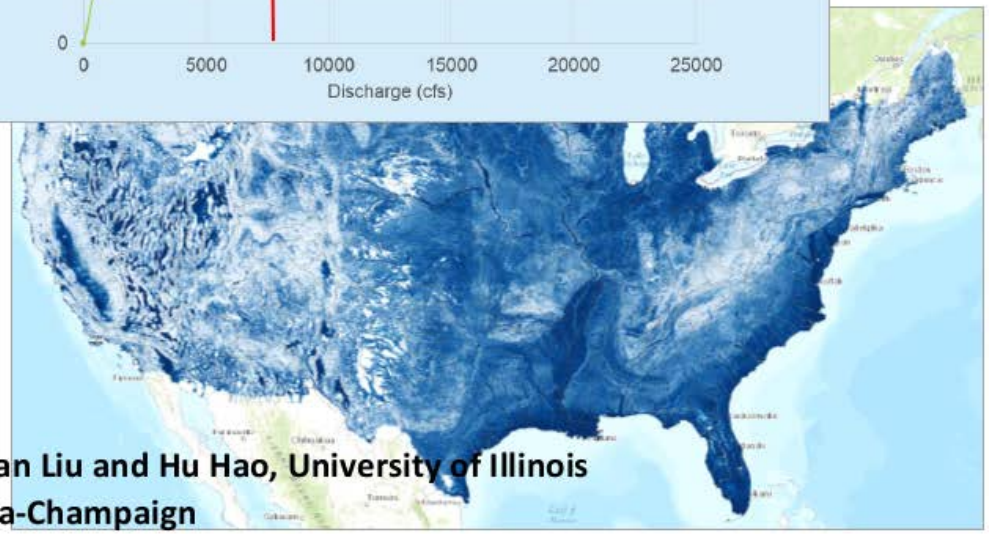
Courtesy: D. Gochis
https://www.cuahsi.org/uploads/cyberseminars/David_Gochis_Presentation.pdf



1



2

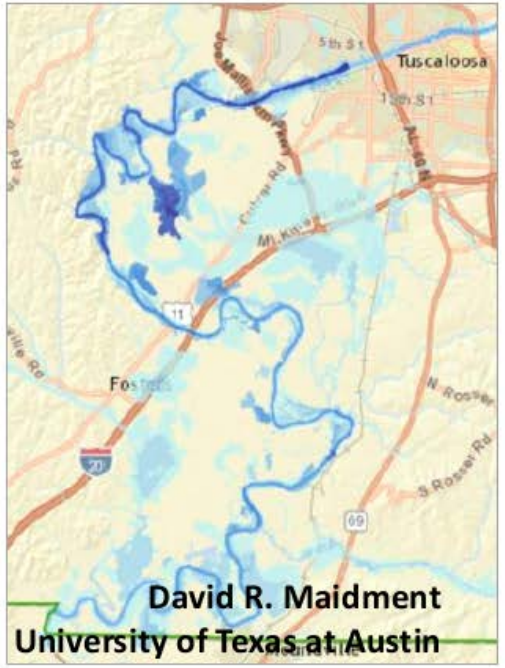


3

1. Forecast discharge with National Water Model

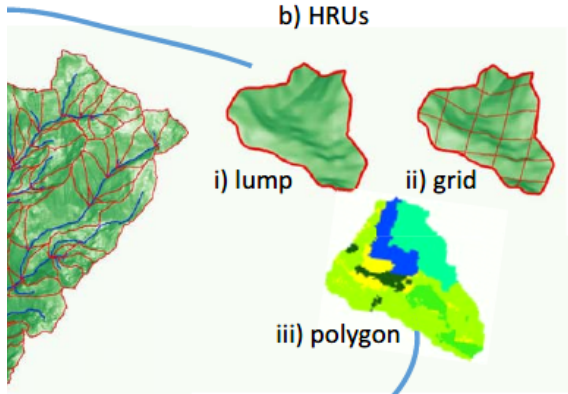
2. Convert discharge to depth using rating curve

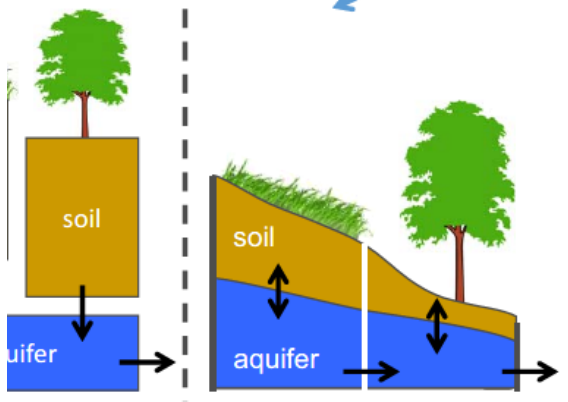
3. Convert depth to inundation using HAND (relative elevation of land surface cell above cell in NHDPlus stream to which it flows)



Source: Yan Liu and Hu Hao, University of Illinois at Urbana-Champaign

VIC-GRU)





polygon), (b) HRUs (single unit, grid, polygon), and (c) the connection vertical soil column corresponds to a single HRU, and there can be HRU example (Figure 2b-iii) the riparian HRU was delineated using 011; *Nobre et al.*, 2011] and the remaining hillslope areas were hen identifying hydrologically similar areas (considering radiation urations of GRUs and HRUs are possible, which may be optionally erarchy of scales.