VARIABLE INFILTRATION CAPACITY (VIC) MODEL

ERT 474/574

Open-Source Hydro Data Analytics

Oct 22nd 2025

University at Buffalo The State University of New York

Announcement

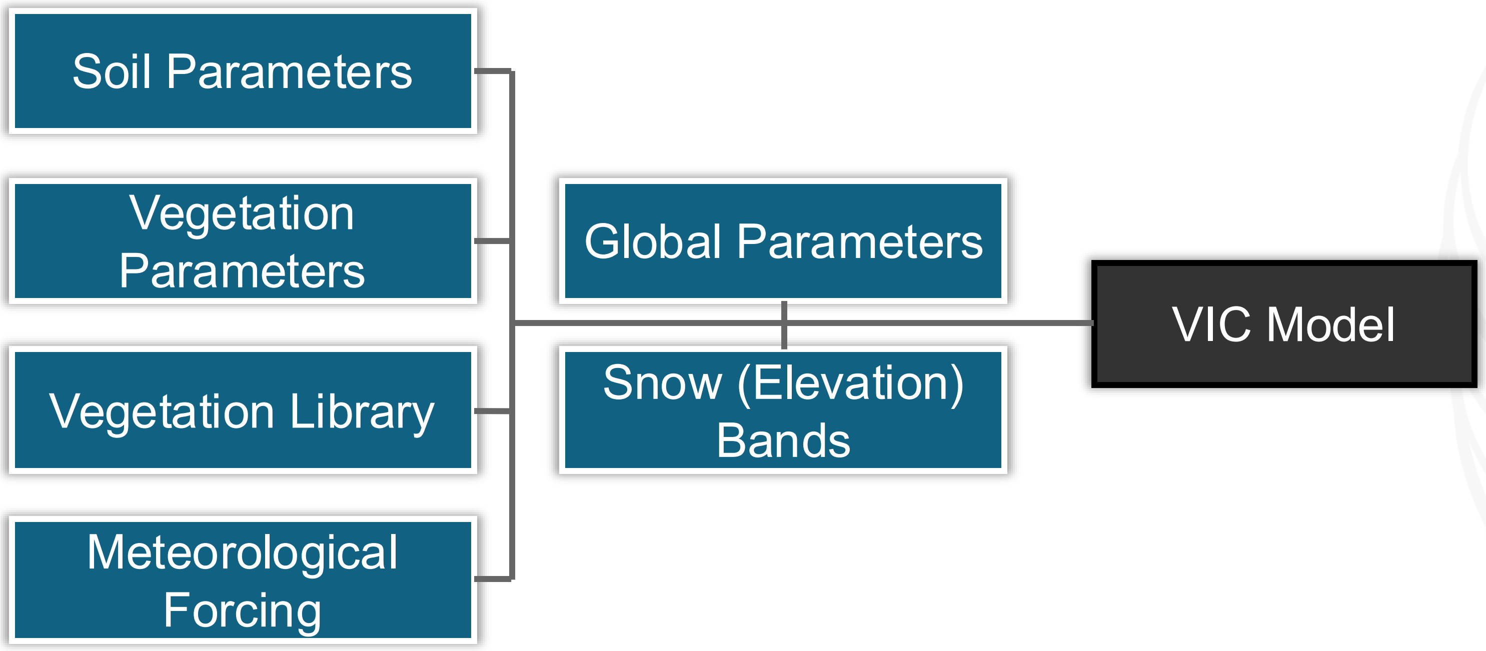
- Mid-term
  - How did it go?
  - A small reality check
  - All the codes there will be evaluated (No matter they successfully run or not)

Final project – Hydrologic model

- Conduct a hydrologic modeling study for your favorite River Basin!
  - Set up a hydrologic model for one basin!
  - Evaluate the model performance by comparing it with USGS or other existing observations.
  - Identify the biases and improve modeling performances
  - Submission: oral presentations and final reports
    - Final reports need to follow the format of a scientific journal article, including an introduction, methodology, results, and discussion

The VIC Model Workflow

Input



Output

- Soil Moisture
- Evapotranspiration
- Surface/Subsurface runoff
- Snow Water Equivalent

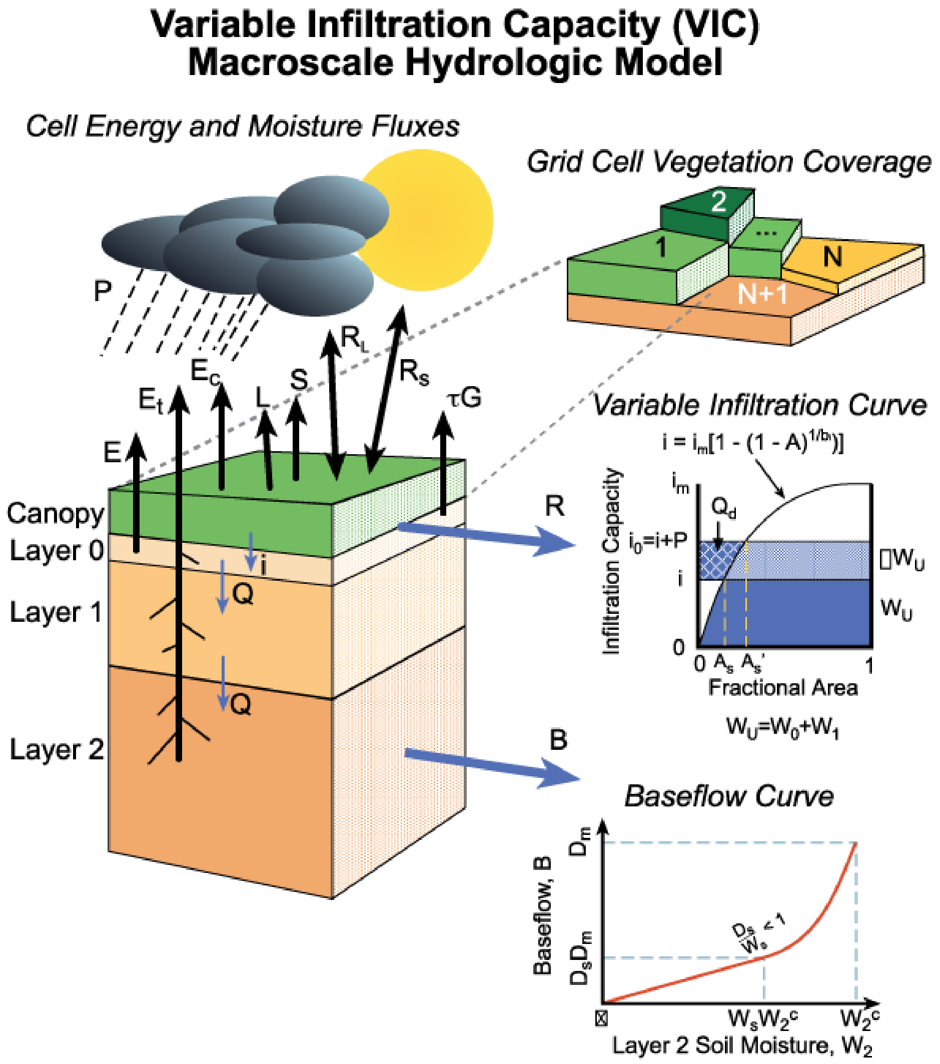
Image derived from VIC Documentation: https://vic.readthedocs.io/en/master/Overview/ModelOverview/

An Overview of the VIC Model

- Hydrology model comparison/selection
- VIC model features
  - Cell size
  - Sub-grid representations
- VIC model processes
  - Vegetation
  - Snow
  - Evapotranspiration
  - Runoff/Infiltration
  - Baseflow

The VIC Model

- The **Variable Infiltration Capacity (VIC)** Model
- **Grid-based** land surface representation
- Simulates land surface-atmosphere fluxes of **moisture** and **energy**
- Developed for coupled Land surface model (LSM) – Global Circulation Model (GCM) simulations
  - Considered **a research model**
- **Open-source** development



Source: https://vic.readthedocs.io/en/master/Overview/ModelOverview/

LSM - Traditional Hydro Model Differences

	Traditional Hydrology Model	LSM Scheme
Purpose	Flood forecasting, water supply	For inclusion in a GCM as a land surface scheme
Fluxes	Water balance is more important than energy balance	Both water and energy balance is important
Model representation	Mainly conceptual models (parameters are not physically based such as the CN model)	More physically based formulation (e.g., hydraulic conductivity)
Vegetation	Implicitly simulated	Explicitly simulated
Run	Lumped parameters	Grid-based
Function	Off-line simulations	Dynamic coupling with GCM or offline simulations

Hydrology Model Selection

- Model selection depends largely on the applications of models
  - Somewhat based on technical expertise
- Many studies have investigated model selection, parameterization, and calibration effects on results
  - Model selection has a major effect
  - Should understand model components and physical representations for application.

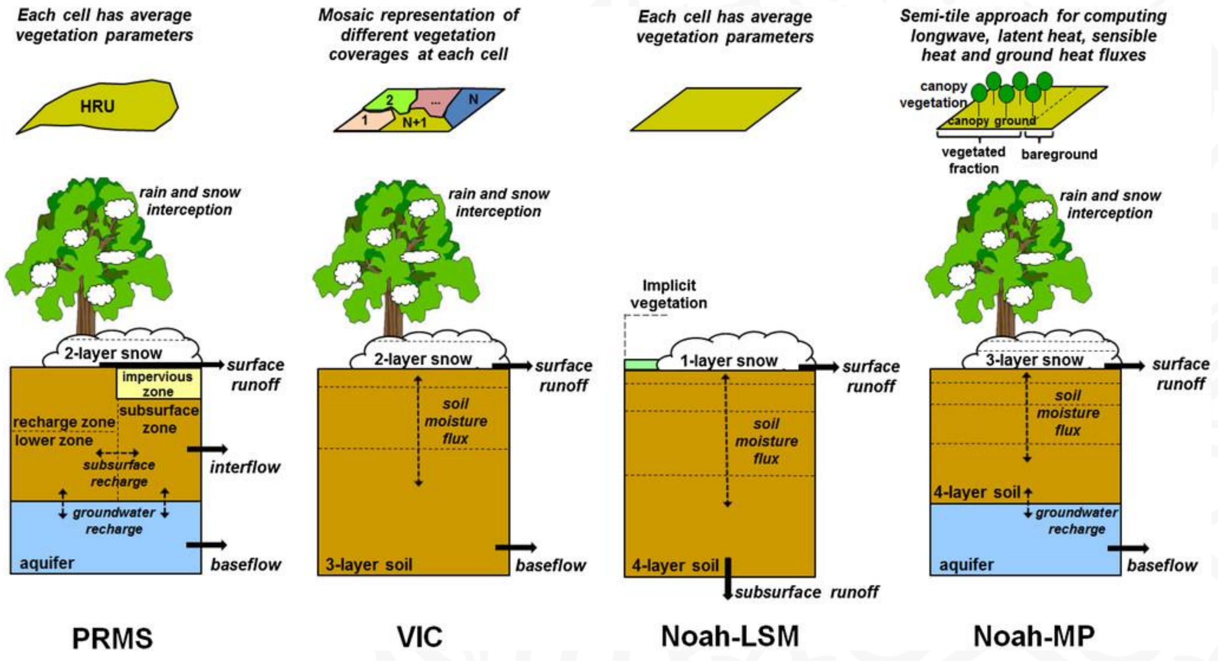
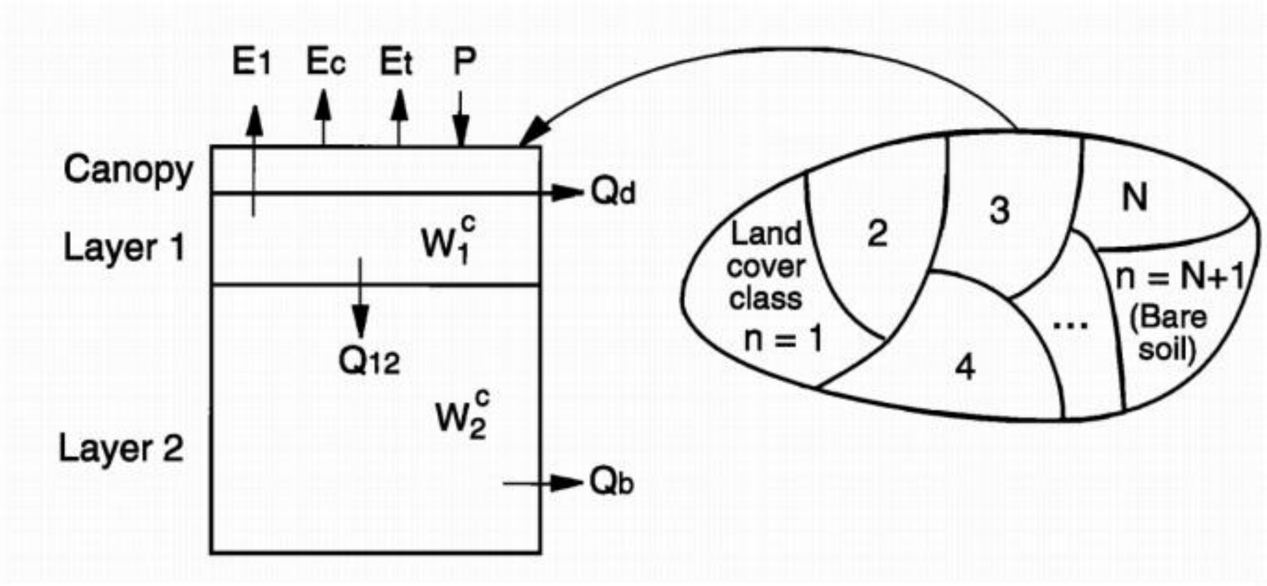
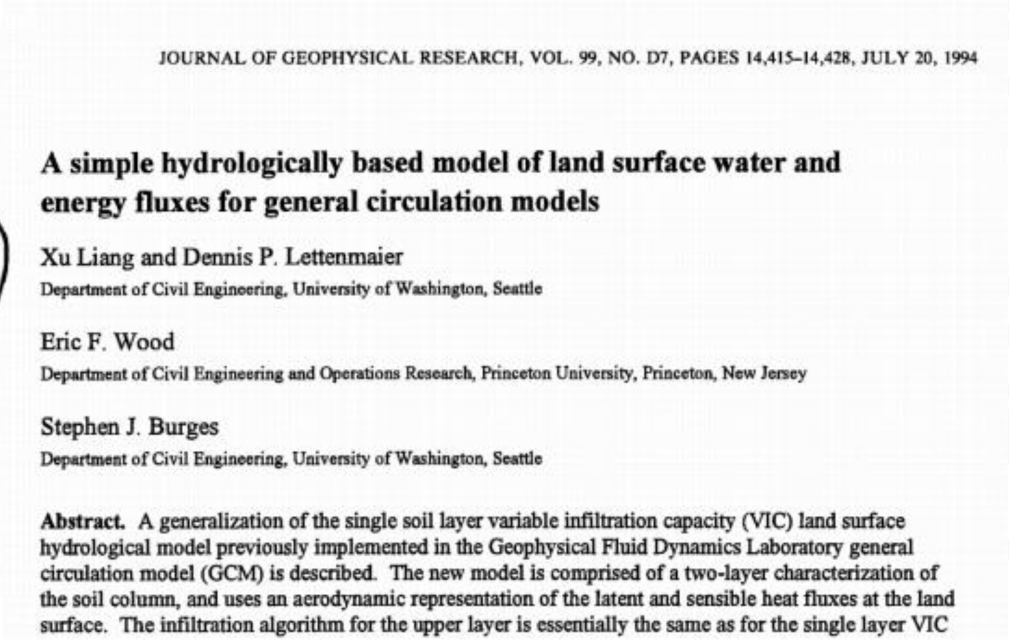


Image from Mendoza et al., 2015. DOI: JHM-D-14-0104.1

Origins of VIC

- Developed by Liang et al. (1994)
- Two-layer soil-vegetation model
- **Physically-based model** to be coupled with climate models




JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 99, NO. D7, PAGES 14,415–14,428, JULY 20, 1994

A simple hydrologically based model of land surface water and energy fluxes for general circulation models

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Abstract. A generalization of the single soil layer variable infiltration capacity (VIC) land surface hydrological model previously implemented in the Geophysical Fluid Dynamics Laboratory general circulation model (GCM) is described. The new model is comprised of a two-layer characterization of the soil column, and uses an aerodynamic representation of the latent and sensible heat fluxes at the land surface. The infiltration algorithm for the upper layer is essentially the same as for the single layer VIC

Image from Liang et al., 1994.

VIC Features

- Each grid cell is simulated independently
  - Only water entering cell is from atmosphere (precipitation)
- Can represent sub-grid vegetation/land cover
- Can represent sub-grid elevation variability (snow bands)
- Daily or sub-daily time step
- Multiple soil layer depths
- Routing of streamflow is performed independently using a separate model
  - Typically the Lohmann et al. [1996; 1998] routing model
  - We will cover the routing of streamflow in a separate lecture.
- Deep groundwater is not considered within the model

VIC Grid Cell Size

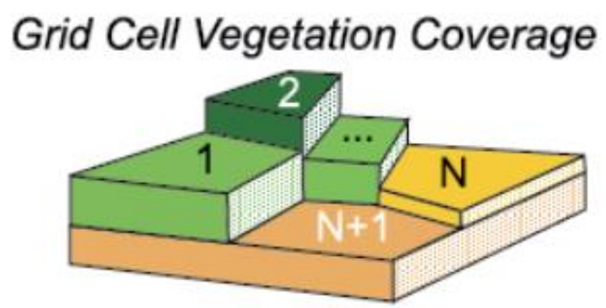
- Grid cells are simulated independently of each other
  - No channel flow, sub-surface flow, or recharge to soil from rivers
- Assumes: **vertical fluxes are much larger than horizontal fluxes**
- Assumption satisfied with **large grid cell (>3km to ~2° resolution)**

- Additional assumptions:
  - Groundwater flow is small relative to surface and near-surface flow
  - Lakes/wetlands do not have significant channel flow
  - Flooding (over banks) is insignificant

- All are usually satisfied if the grid cell is large enough

Sub-Grid Representation: Vegetation

- Spatial distribution and parameters for vegetation classes are specified within input files
- Energy and water balance terms are **computed independently for each vegetation class**
- Each class has a **different parameterization**:
  - Leaf-Area Index
  - Rooting Depth
  - Surface Roughness
  - etc.



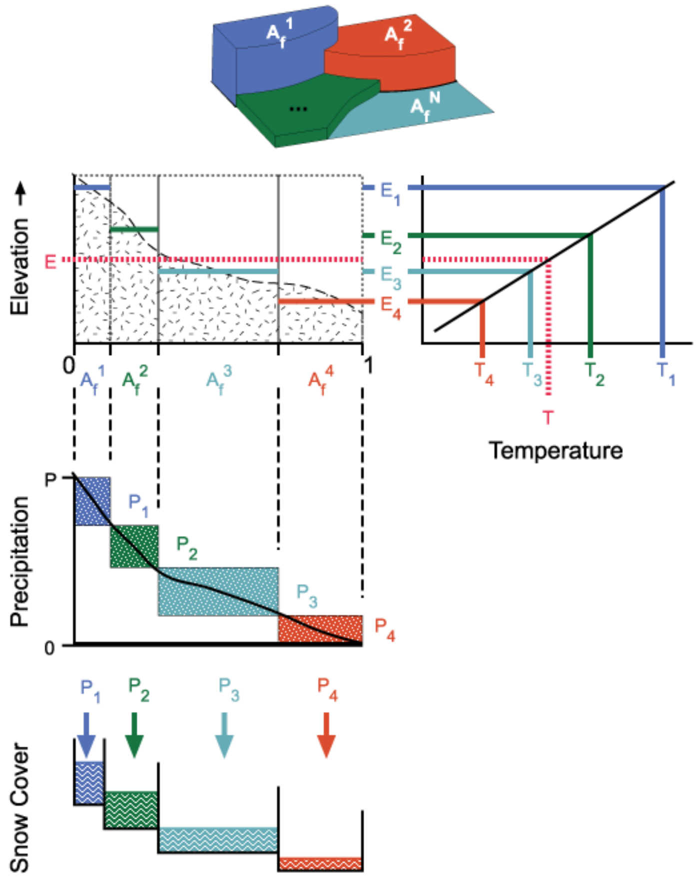
- Classes **must add up to 100% area** or VIC's **bare soil scheme is used for the remainder**
- Example: 33% Forest, 36% Grassland
  - What's the bare soil percentage?
  - **100 – 33 – 36 =31% bare soil**

Source: https://vic.readthedocs.io/en/master/Overview/ModelOverview/

Sub-Grid Representation: Elevation

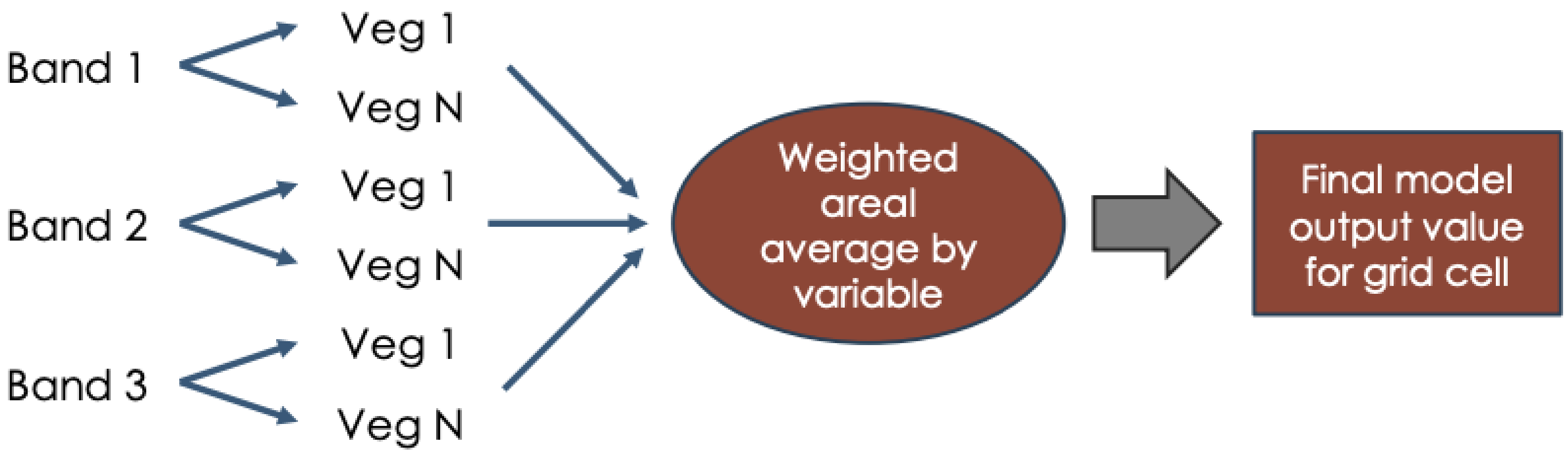
- Simulates **orographic effects** on precipitation/snowfall and snowpack processes
- Important for representing the differences in **snow accumulation and snow melt timing** between high and low elevations
- **User-specified** snow (elevation) bands
  - Fractional area and mean elevation for each band
- Mean pixel **temperature is lapsed to each elevation band**
  - Precipitation falls as either liquid or solid depending on the lapsed temperature

VIC Snow Elevation Bands



Sub-Grid Representation: Aggregation

- Sub-grid processes are combined through **weighted areal average**
- Computed by elevation bands and then vegetation cover
  - **Order of operations is important**



- More elevation bands and vegetation types significantly increase computation time!

Quiz Question

With the VIC model, what is the smallest grid cell size in which we can run the model and still have a representation of the physics, and why?

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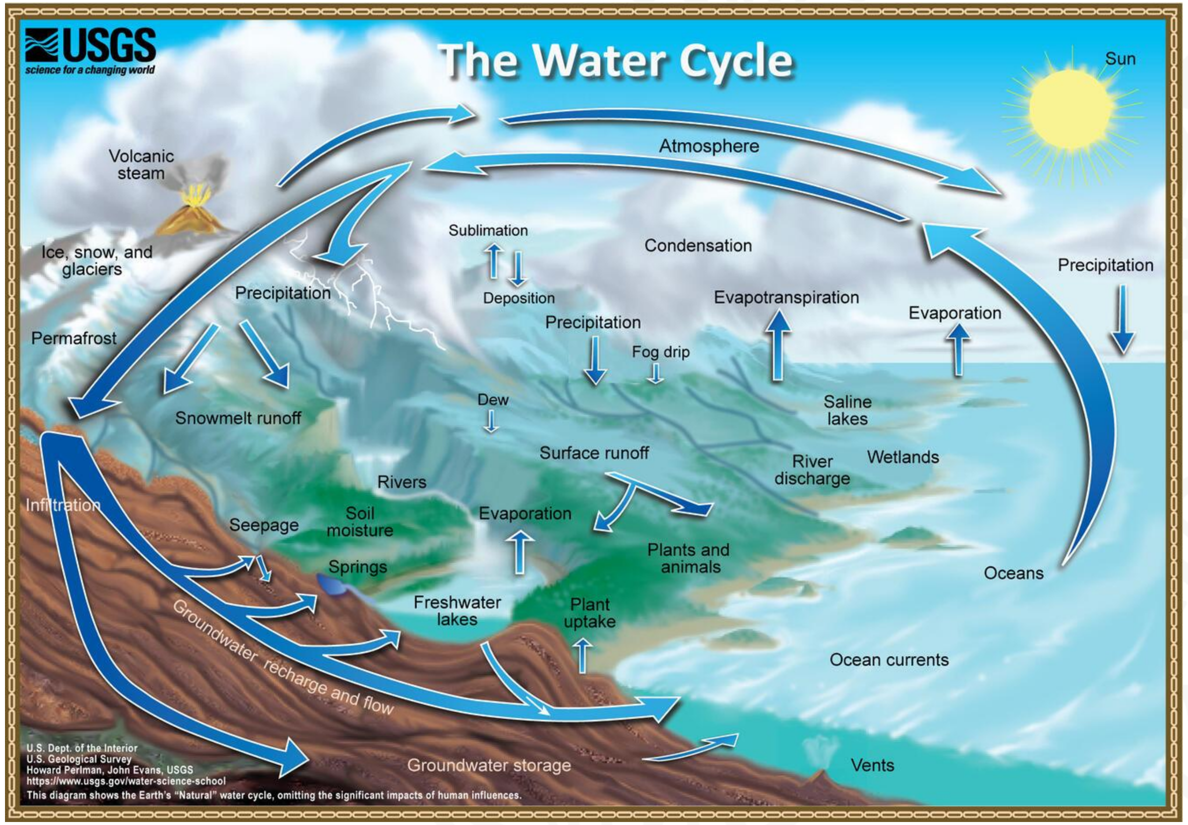
With the VIC model, what is the smallest grid cell size in which we can run the model and still have a representation of the physics, and why?

3km. We would not recommend running VIC for grid cells smaller than 3km.

Hydrologic Process Representation

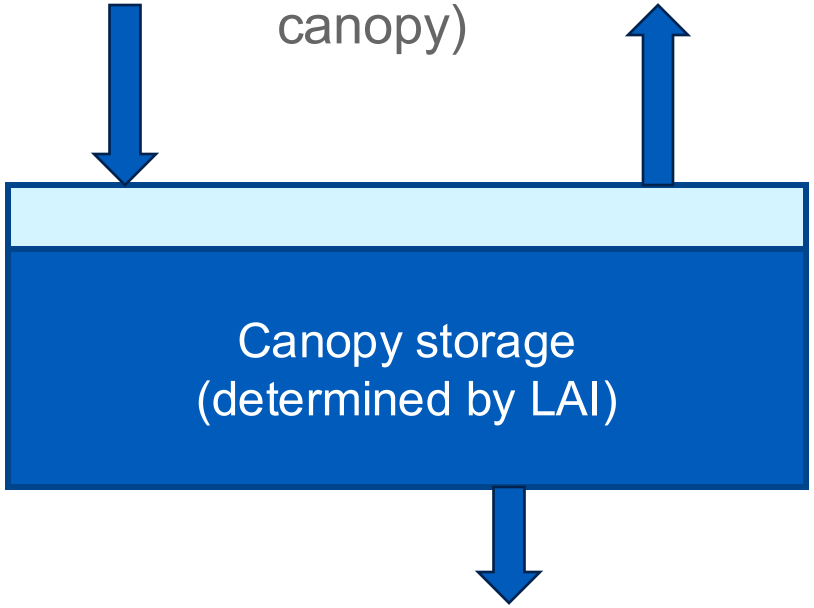
- Requires detailed parameterization
  - Important for climate-sensitive regions
  - Parameterization versus Parameters
- Contains modules and options to capture specific processes



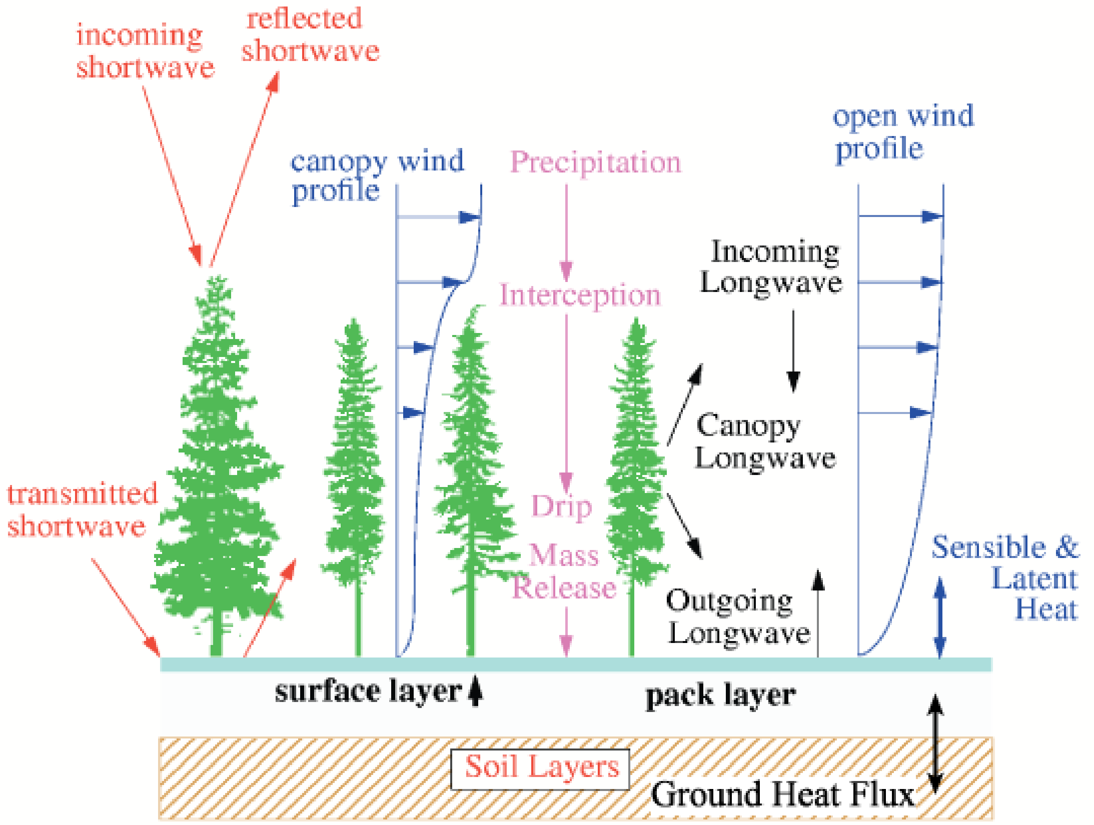
Vegetation Canopy

Precipitation

Canopy evaporation (wet canopy or snow) or Transpiration (dry canopy)



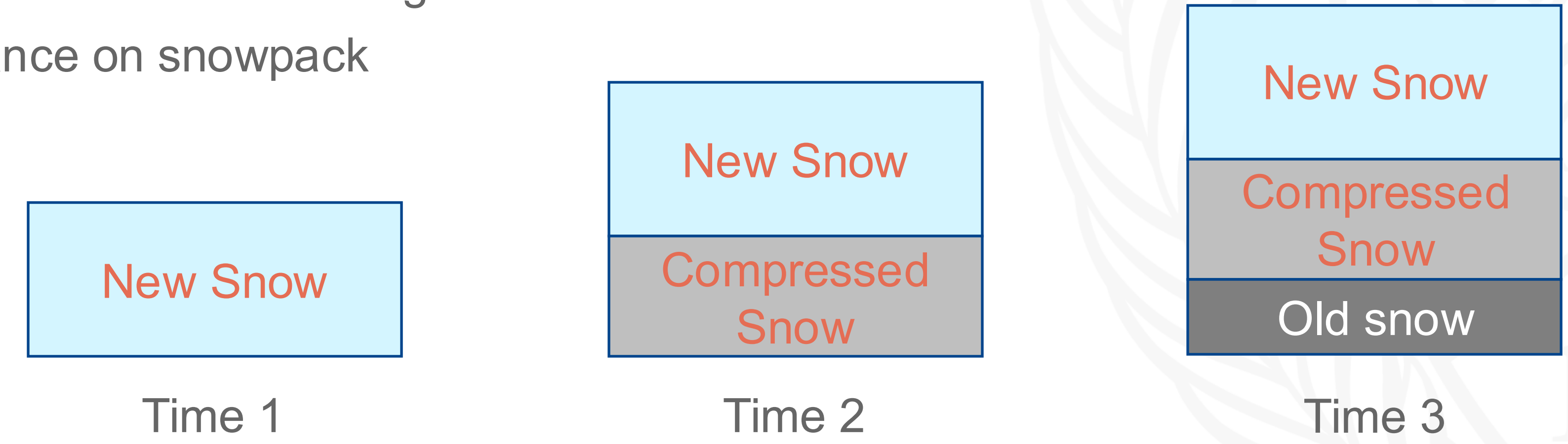
Canopy “throughfall” occurs when additional precipitation exceeds the canopy storage capacity in the current time step



Source: https://vic.readthedocs.io/en/master/Overview/ModelOverview/

Snow Simulations

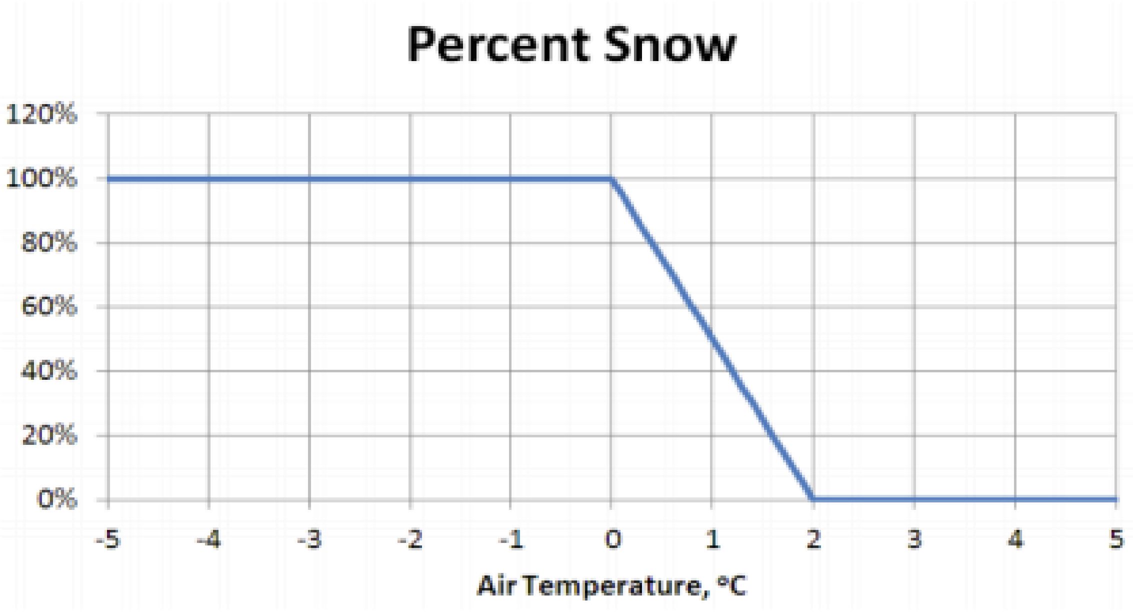
- Snow within the vegetation canopy is directly related to LAI
- Uses quasi two-layer energy balance model at the snow surface
    - Thin surface layer (solving the energy balance at the pack surface)
    - Pack layer
- Albedo and snowpack size evolve with snow ages
- We can calibrate snow surface roughness and albedo to affect the energy balance on snowpack



Rain-Snow Partitioning

- VIC used a **simple (linear) method** to determine the **percentage of liquid (rain) or solid (snow) precipitation**
- Example: Rain Minimum = 0.0 °C
- Snow Maximum = 2.0 °C
- The **rain minimum and snow maximum parameters are calibratable**

- For this example, 0.5°C would produce 75% snow and 25% rain



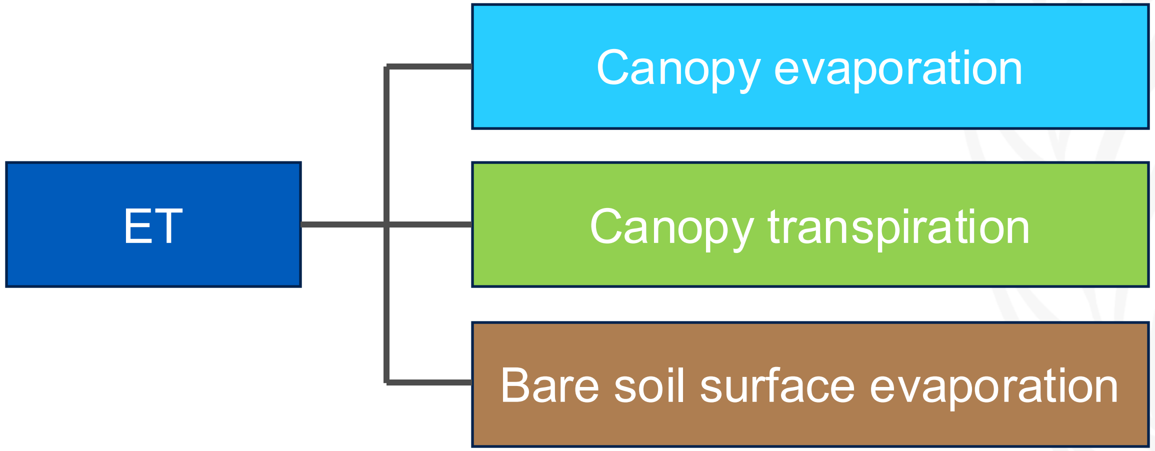
Evapotranspiration Simulation

- Physically-based Penman Monteith approach [Monteith, 1965]

$$ET = \overset{\text{Volume flux rate}}{\frac{\Delta(R_n - G) + \rho_a c_p\,(\delta e)\,g_a}{(\Delta + \gamma\,(1 + g_a/g_s))\,L_v}}$$

Δ = Rate of change of saturation specific humidity with air temperature. (Pa K^{-1})
R_n = Net irradiance (W m^{-2}), the external source of energy flux
G = Ground heat flux (W m^{-2}), usually difficult to measure
c_p = Specific heat capacity of air (J kg^{-1} K^{-1})
ρ_a = dry air density (kg m^{-3})
δe = vapor pressure deficit (Pa)
g_a = Conductivity of air, atmospheric conductance (m s^{-1})
g_s = Conductivity of stoma, surface or stomatal conductance (m s^{-1})
γ = Psychrometric constant ($\gamma \approx 66$ Pa K^{-1})

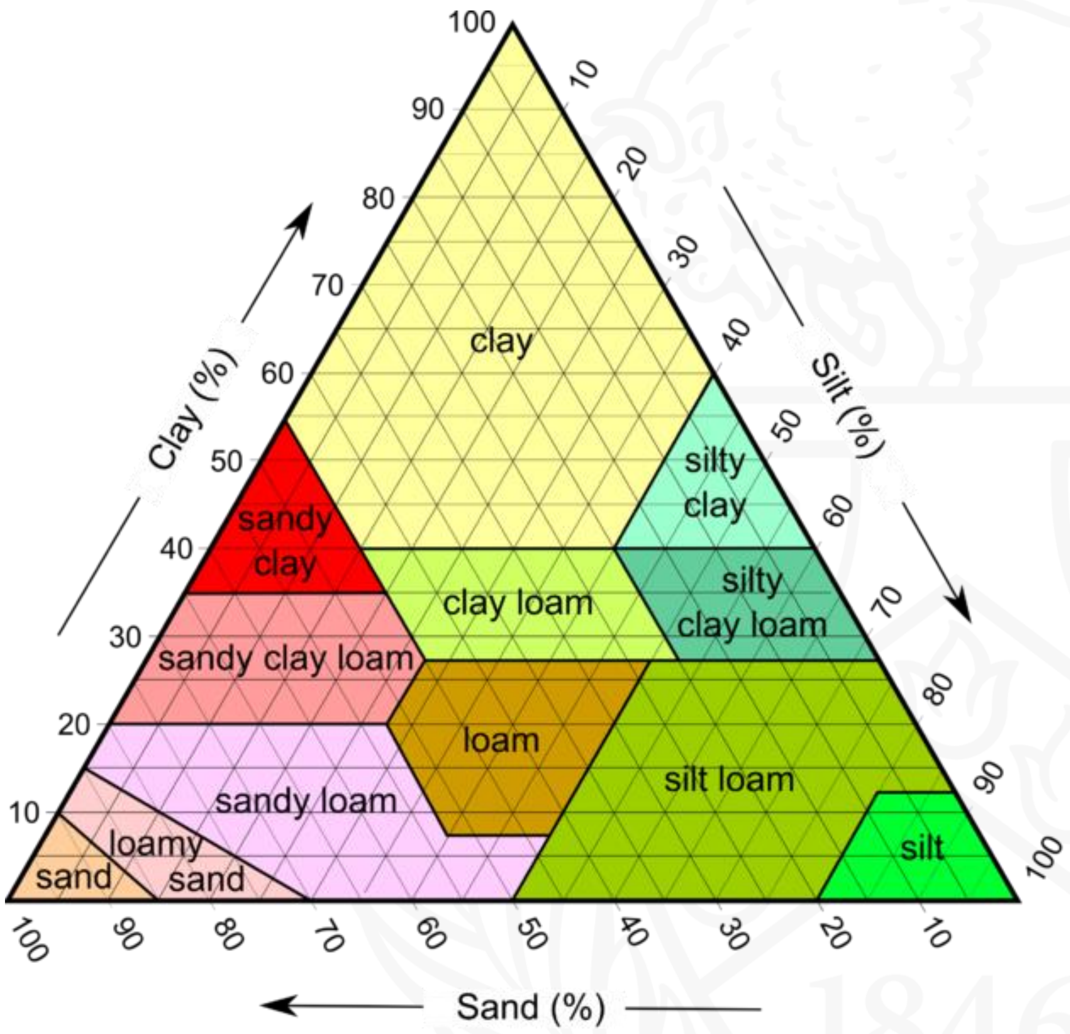
- Made up of three components for each elevation band and vegetation type



- Bare soil calculations are similar but include resistance terms for soil-atmosphere moisture transfer

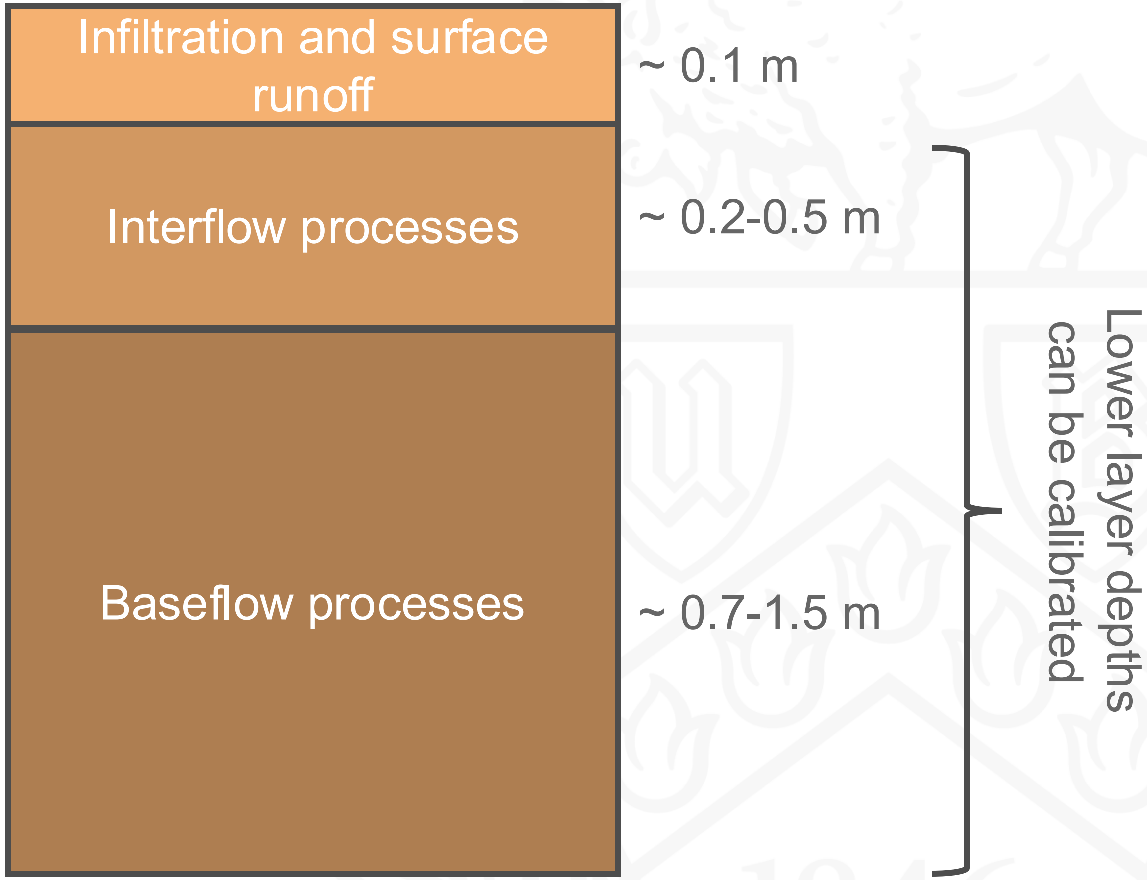
Parameterization of Soils

- Soil information is poorly known
- **Pedotransfer functions**
    - Changing what we have into what we need
    - Soil texture info to physical units
    - Soil pedotransfer table
- Soil texture information is used to estimate:
    - Porosity
    - Ksat
    - Field capacity
    - Wilting point
    - Residual capacity
    - And other soil characteristics



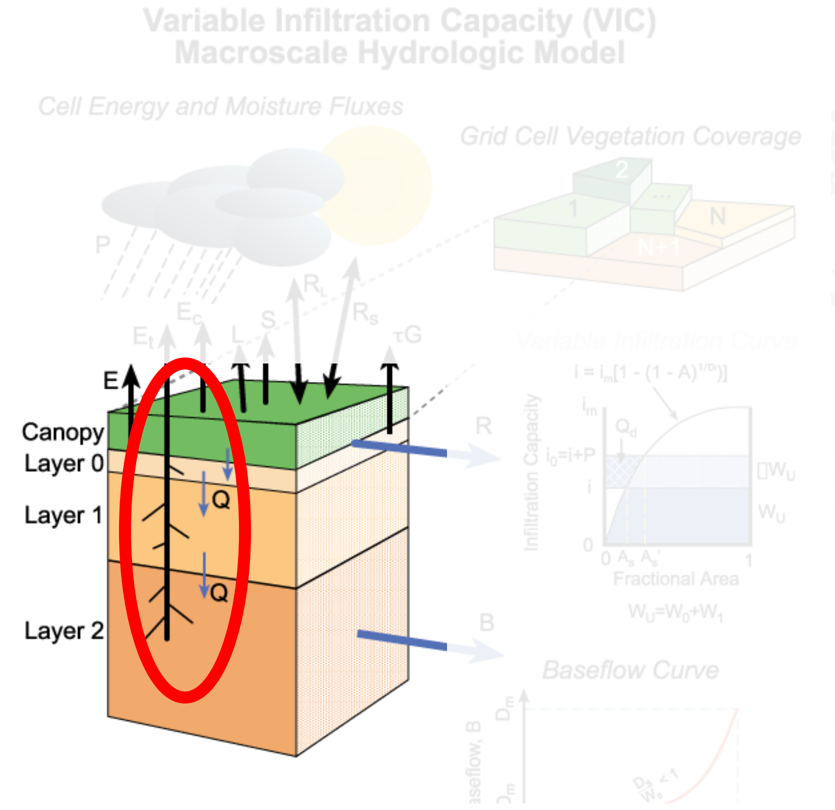
Soil Column

- Parameterize arbitrary number of soil layers at different depths
  - Model requires at least two soil layers for water balance calculations and three soil layers for energy balance calculations
  - No theoretical limit to the number of layers
- **Typically, three layers** are defined for simulations
  - NLDAS VIC 3 layers (approx. 0-0.15, 0.15-0.55, and 0.55-1.35 m)
  - GLDAS VIC 3 layers (0-0.1, 0.1-1.6, and 1.6-1.9 m)



Rooting Depths

- Rooting depths are independent of soil layer depths
- Rooting depths and distributions are user-defined
  - Defined for each vegetation type in each grid cell
- Important parameterization for vegetation transpiration calculations
  - Determines available water at soil depths for uptake by vegetation
- Rooting parameterization taken from literature or estimated



Water Resources Research

Research Article | Free Access

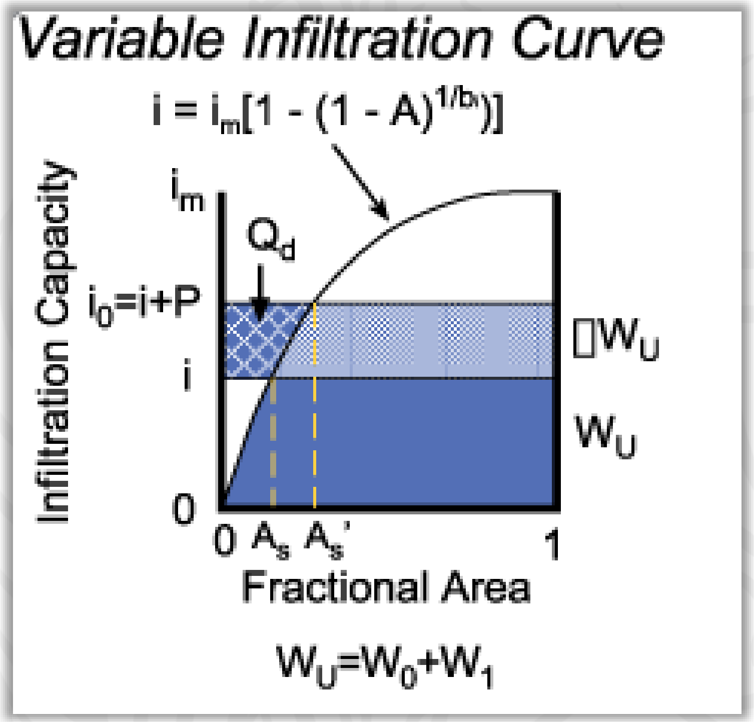
Global estimation of effective plant rooting depth: Implications for hydrological modeling

Yuting Yang, Randall J. Donohue, Tim R. McVicar

First published: 11 October 2016 | https://doi.org/10.1002/2016WR019392 | Citations: 168

Runoff-Soil Infiltration

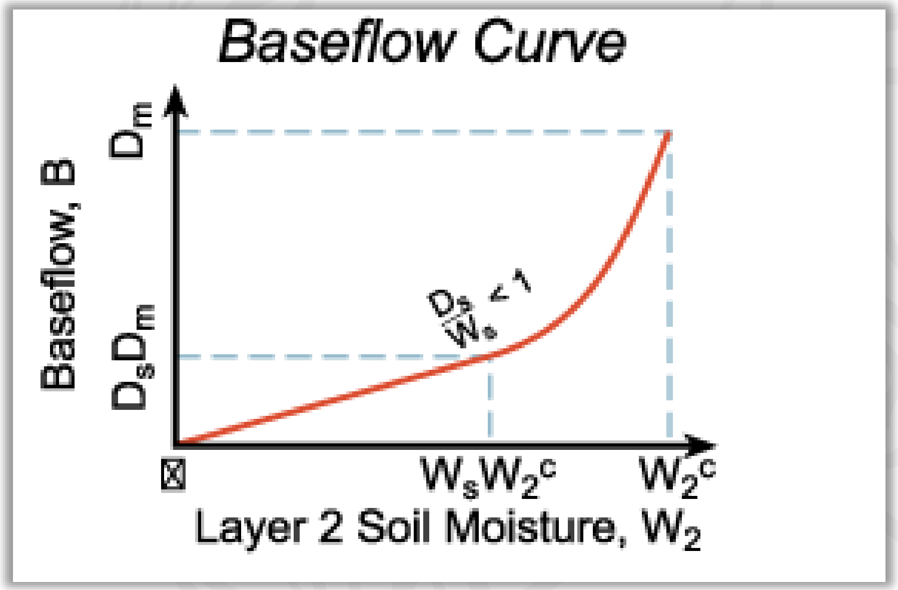
- Surface runoff/soil infiltration defined by the **variable infiltration curve** [Wood et al., 1992]
- Scales maximum infiltration with **a non-linear function** of fractional saturated area
  - Enables runoff calculations **for subgrid-scale areas**
- Curve shape defined by b_{inf} parameter (typically between 10^{-5} and 0.4)
  - Amount of infiltration capacity relative to the saturated gridcell area
- Greater value of b_{inf} yields lower infiltration and more runoff (Q_d)



Sub-surface Flow

- Subsurface flow (baseflow) is estimated using the Arno baseflow model [Francini and Pacciani, 1991]
- Function of soil moisture in the lowest layer
- Linear at low soil moisture content
  - Reduces responsiveness of baseflow during dry conditions
- Non-linear at high soil moisture content
  - Rapid baseflow response during wet conditions

Linear baseflow: $B = \frac{D_S \cdot D_{Smax}}{W_S W_n^c} \cdot W_n$



Baseflow Formulation

- Important to **understand baseflow dynamics and parameterization for calibration**
- Baseflow calculation example: **https://goo.gl/5qFCKM**
- Assume one time step (t1 to t2) and the lowest layer's soil moisture increases from 300 to 310 mm. Find the change in baseflow for the time step using different parameterization
  - Change model parameters for different results

Dsmax [mm]	Ds [-]	Ws [-]	Wnc [mm]	Qbase(t1) [mm day-1	Qbase(t2) [mm day-1	*ΔQbase [mm day-1]*
50	0.2	0.9	50	66.66666667	68.88888889	*2.222222222*
30	0.2	0.6	50	60	62	*2*
30	0.05	0.8	50	11.25	11.625	*0.375*
5	0.05	0.6	50	2.5	2.583333333	*0.08333333333*
5	0.4	0.8	50	15	15.5	*0.5*
5	0.3	0.4	50	22.5	23.25	*0.75*
Soil moisture(t1) [mm]	**Soil moisture(t2) [mm]**					
300	310					

- W_n^c (or W_s, D_{smax}) parameters defined by soil parameters
  - W_n^c = porosity * soil depth

Computational Considerations

- Compiled using free GNU C compilers
  - Can use other compilers but needs to be tested
- Simulation runs cell by cell, can be very **efficiently parallelized by dividing the domain into separate runs**
- VIC is typically run using **LINUX operating systems**
  - Possible to run using Windows OS but not supported
- Simulations usually use about 5 MB of RASM
  - Memory usage does not increase with basin size but simulation time does!
  - Parallelization would require more memory as well.
- **Need a considerable amount of storage** for I/O data
  - Dependent on basin size, time step, etc.

VIC resources

- Current VIC website:
    - https://vic.readthedocs.io/en/master/

- Source Code Availability
    - https://github.com/UW-Hydro/VIC

References

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