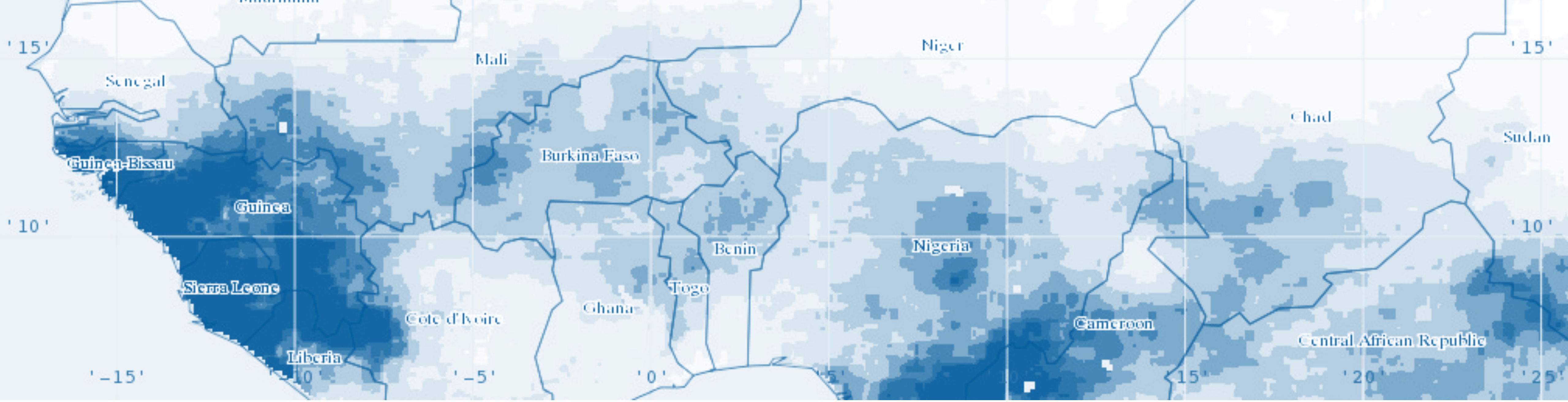

VIC MODEL OVERVIEW

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6 March 2017

VIC/BCSPP Training

Huntsville, AL

OUTLINE

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

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

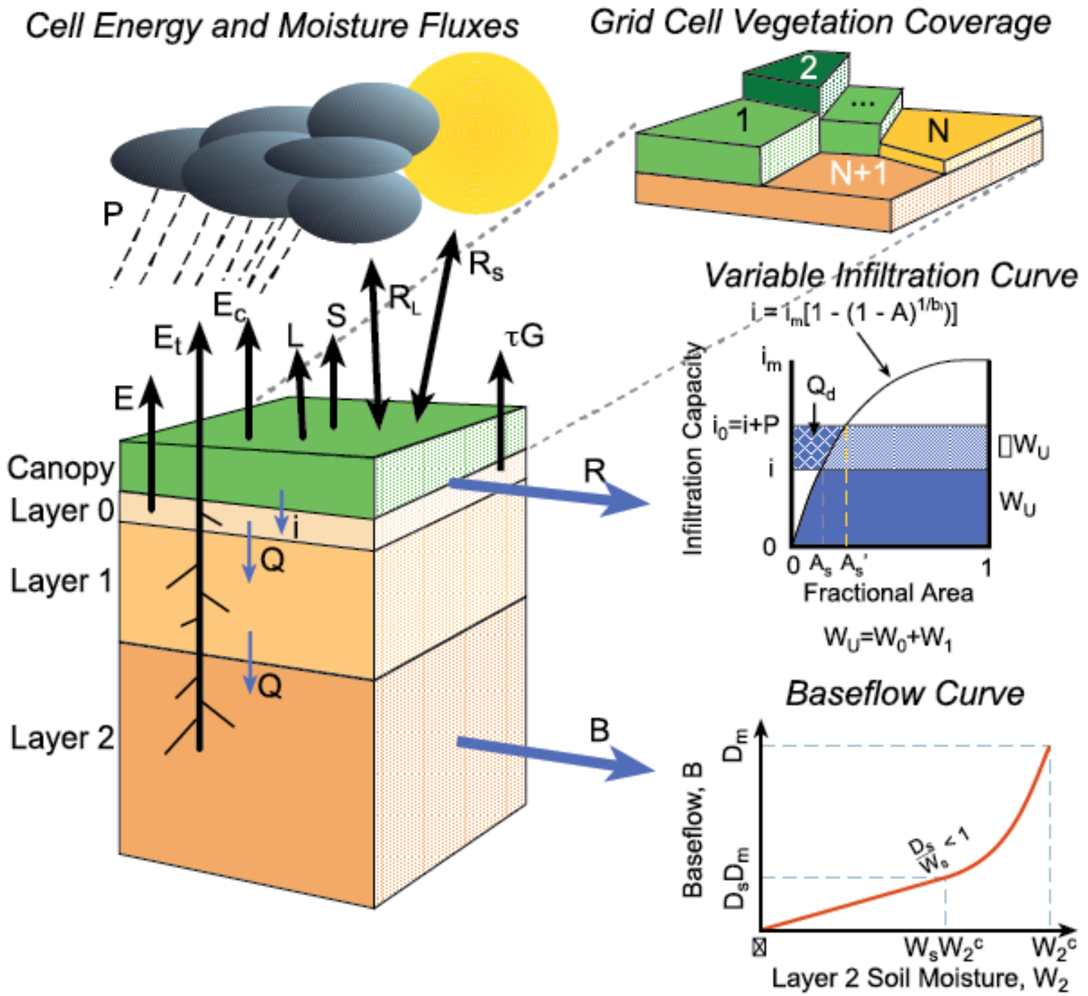


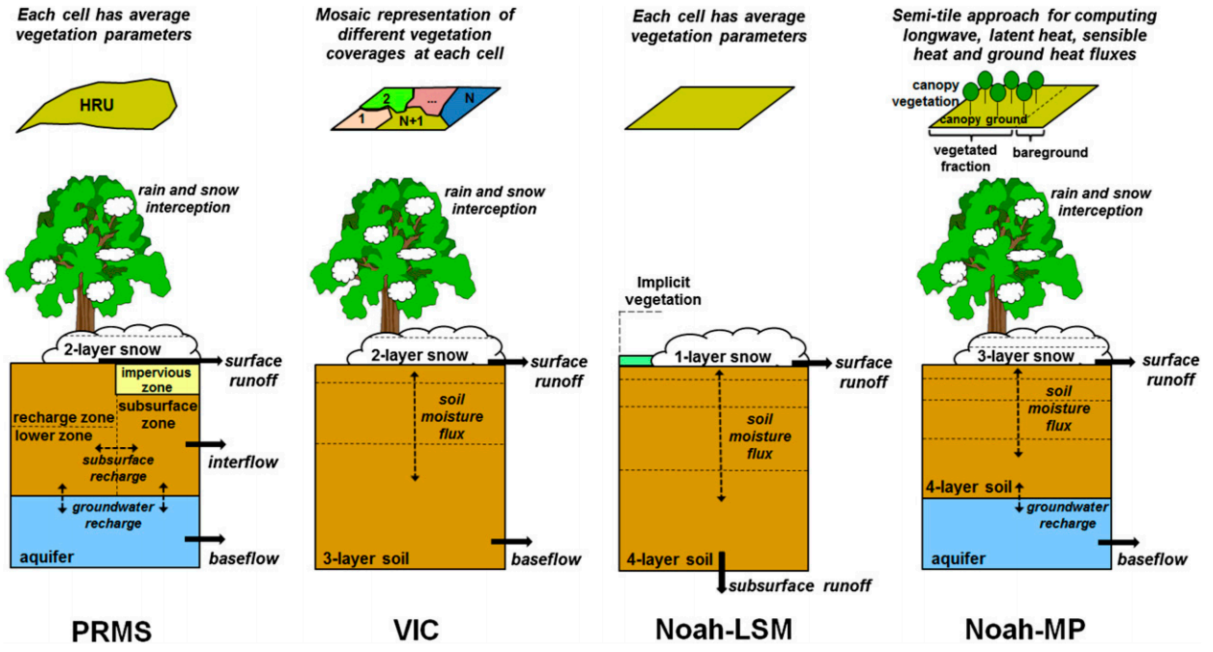
Image from Open Access VIC Documentation:
http://vic.readthedocs.io/en/master/Overview/ModelOverview/

LSM - TRADITIONAL HYDRO MODEL DIFFERENCE

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

HYDROLOGY MODEL SELECTION

- Model selection depends largely on application of model
  - 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



Mendoza et al., 2015 (Open access *J. Hydromet.* Article): http://journals.ametsoc.org/doi/pdf/10.1175/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

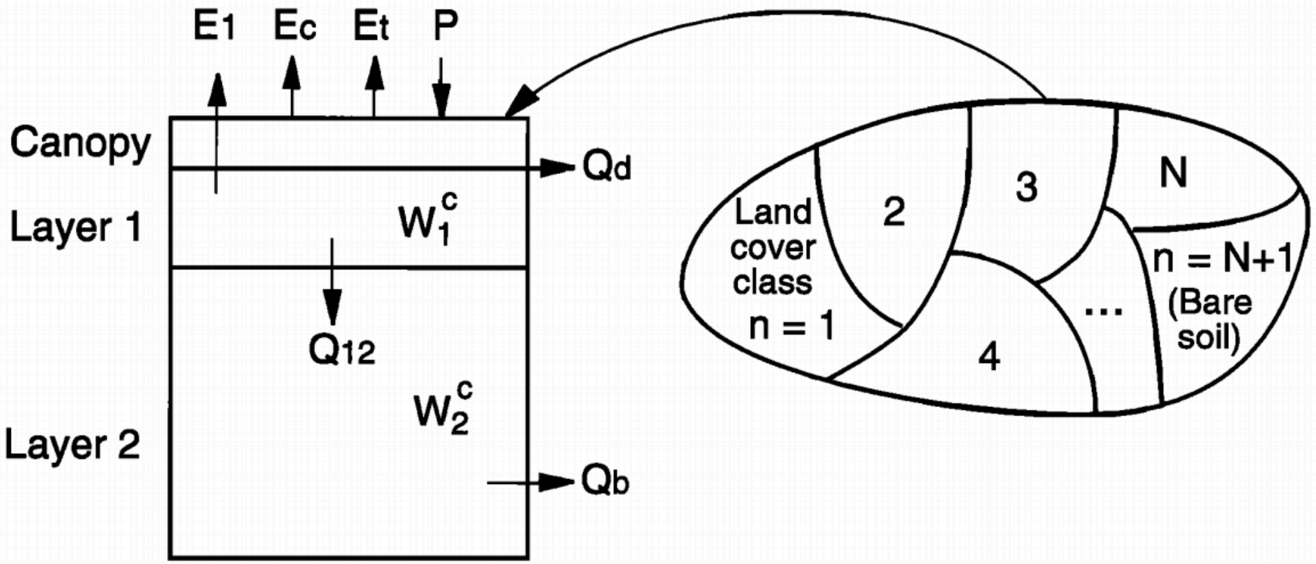


Image from *Liang et al.* [1994] (Open access article):
http://onlinelibrary.wiley.com/doi/10.1029/94JD00483/epdf

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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Stephen J. Burges
Department of Civil Engineering, University of Washington, Seattle

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

VIC FEATURES

- Each grid cell is simulated independently
  - Only water entering cell is from atmosphere
- 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
- Deep groundwater is not considered within the model

VIC GRID CELL SIZE

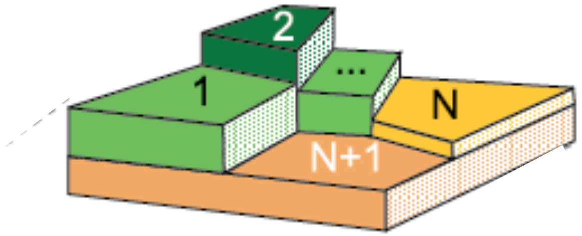
- Grid cells are simulated independently of each other
  - No channel flow, sub-surface flow, or recharge to soil from rivers
- Assumes: **vertical fluxes are much larger than horizontal fluxes**
  - $ET \cdot L \cdot W >> Q \cdot (2L + 2W) \cdot D$
- Assumption satisfied with **large grid cell (1km 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 **different parameterization**:
  - Leaf-area index
  - Rooting depth
  - Surface roughness
  - etc.

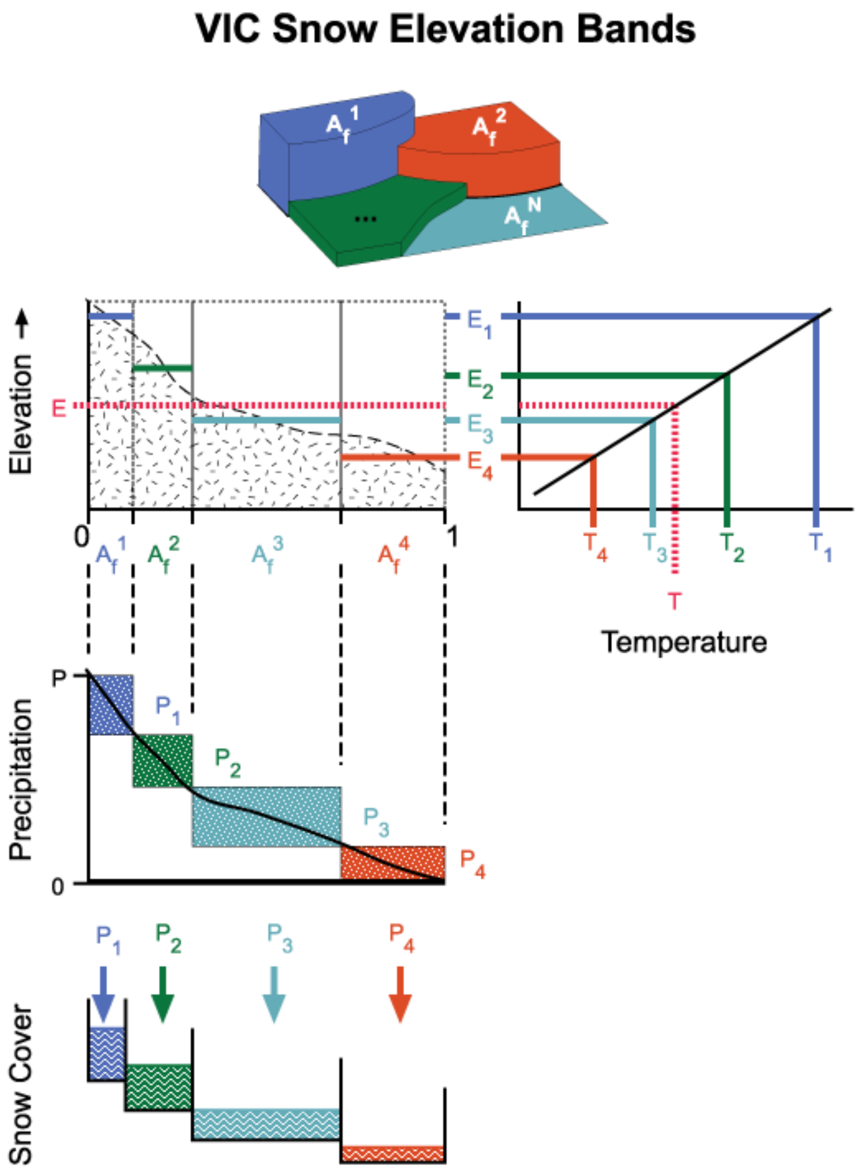


- Classes **must add up to 100% area** or VIC's **bare soil scheme is used for the remainder**
- Example: 33% Forest, 36% Grassland
  - (100 – 33 – 36 = 31% bare soil)

Image from Open Access VIC Documentation:
http://vic.readthedocs.io/en/master/Overview/ModelOverview/

SUB-GRID REPRESENTATION: ELEVATION

- Simulates orographic effects on precipitation/snowfall and snow pack processes
- Important for representing the differences in snow accumulation and snow melt timing between high and low elevations
- User specified snow (elevation) bands
  - Factional 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



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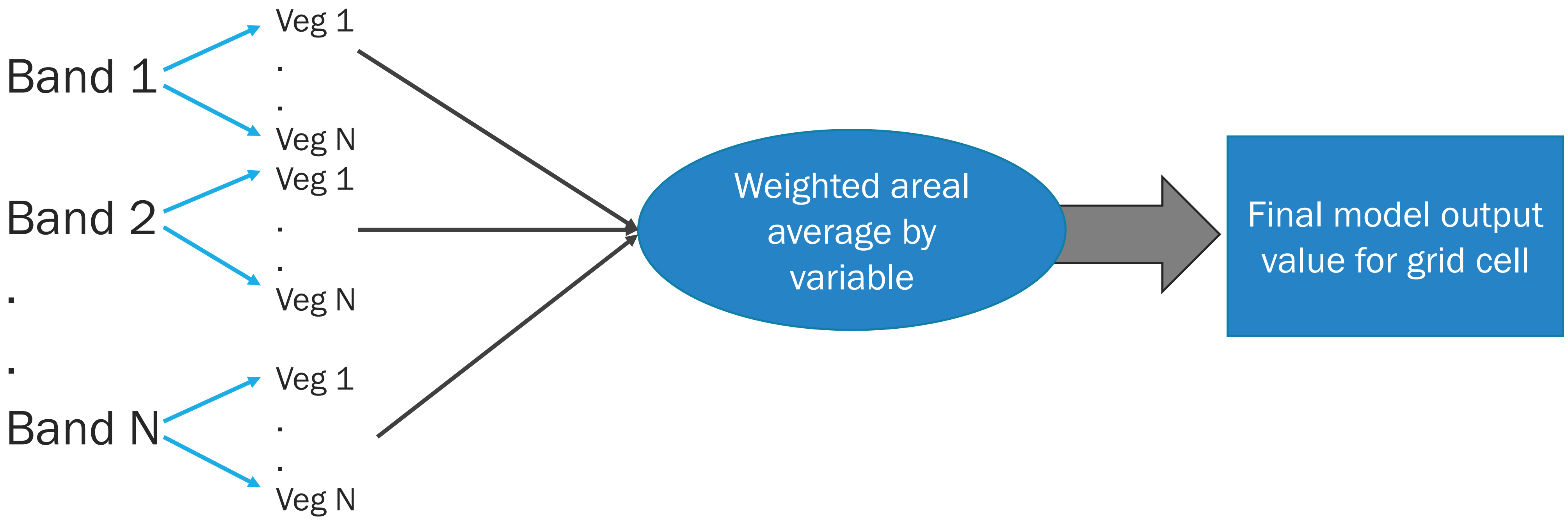
SUB-GRID REPRESENTATION: AGGREGATION

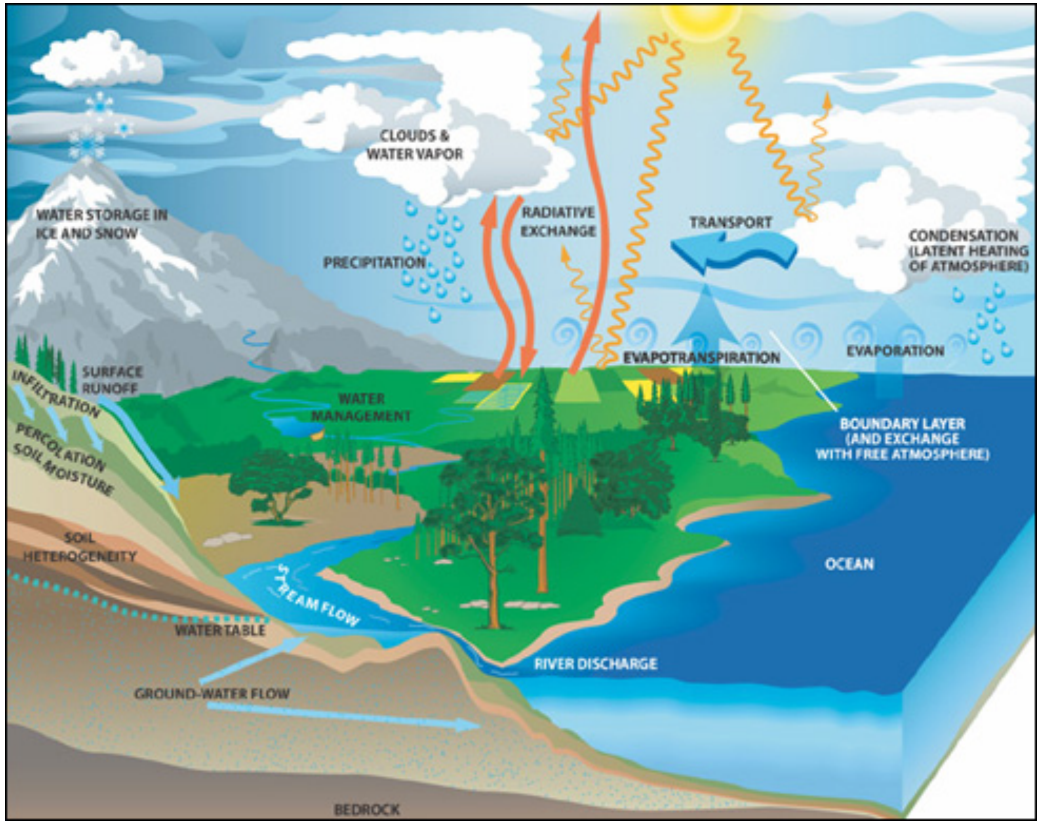
- Sub-grid processes are combined through **weighted areal average**
- Computed by elevation bands and then vegetation cover
  - **Order of operations is important**



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

HYDROLOGIC PROCESS REPRESENTATION

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

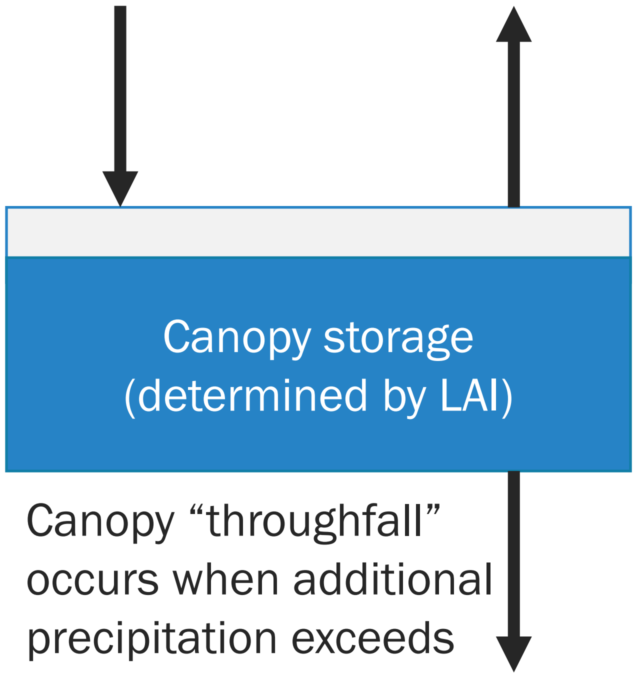


https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle

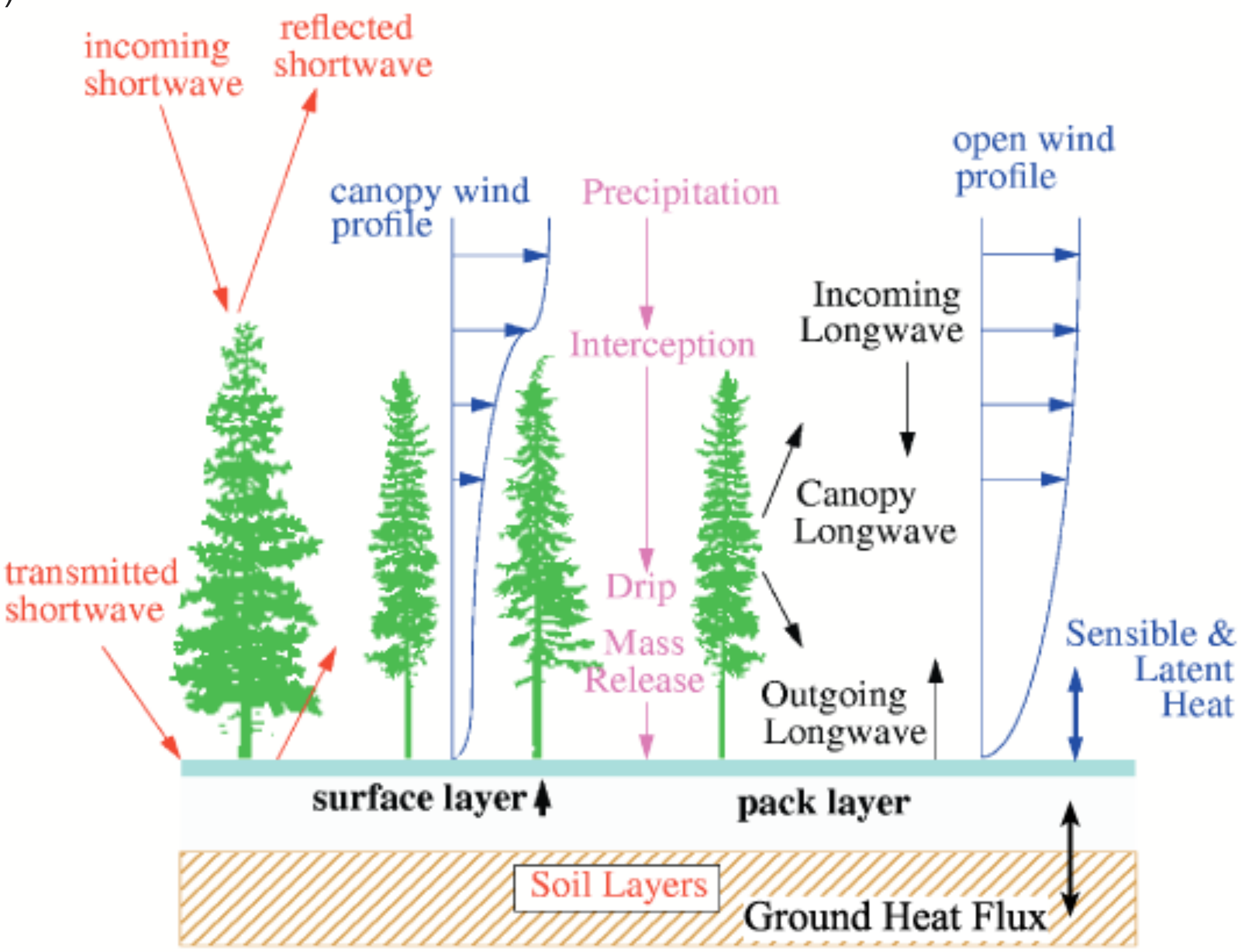
VEGETATION CANOPY

Precipitation

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



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



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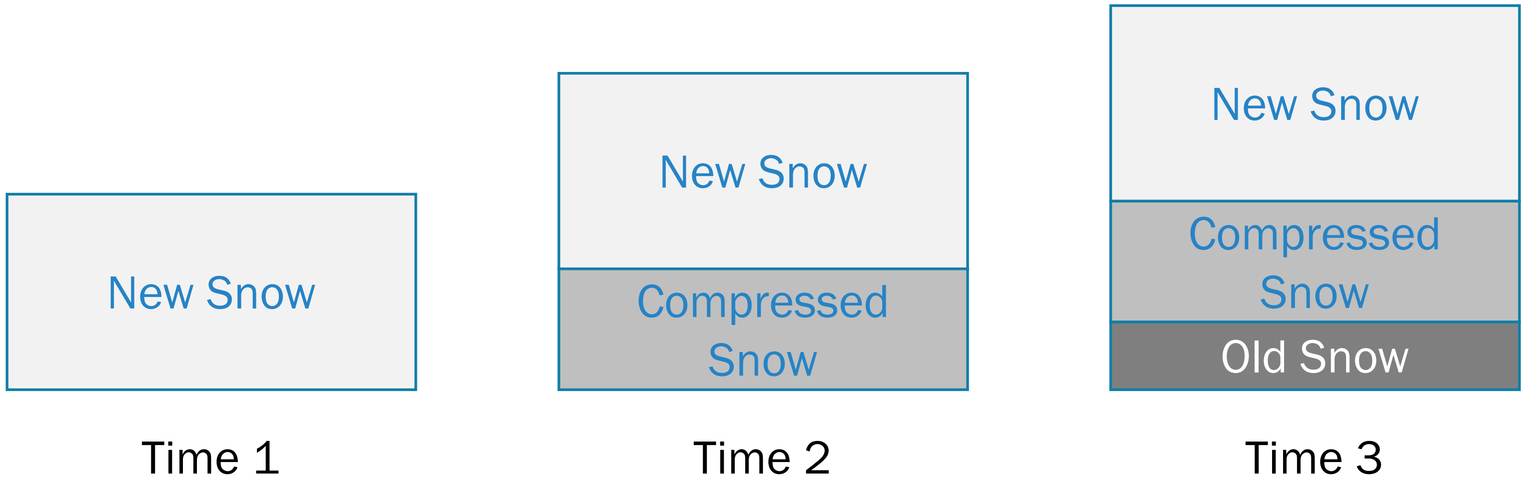
SNOW SIMULATIONS

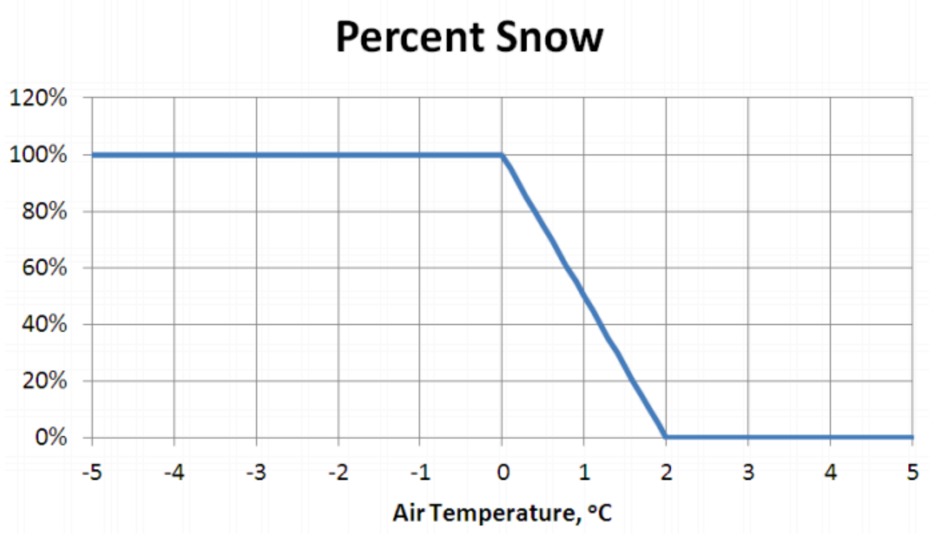
- Snow within the vegetation canopy is directly related to LAI
- Uses **two-layer energy balance model** at snow surface
  - Thin surface layer
  - Pack layer
- Albedo and snow pack size evolves with snow ages
- Requires calibration of snow surface roughness



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
- Requires calibration of the rain minimum and snow maximum parameters
  - For this example, 0.5°C would produce 75% snow and 25% rain

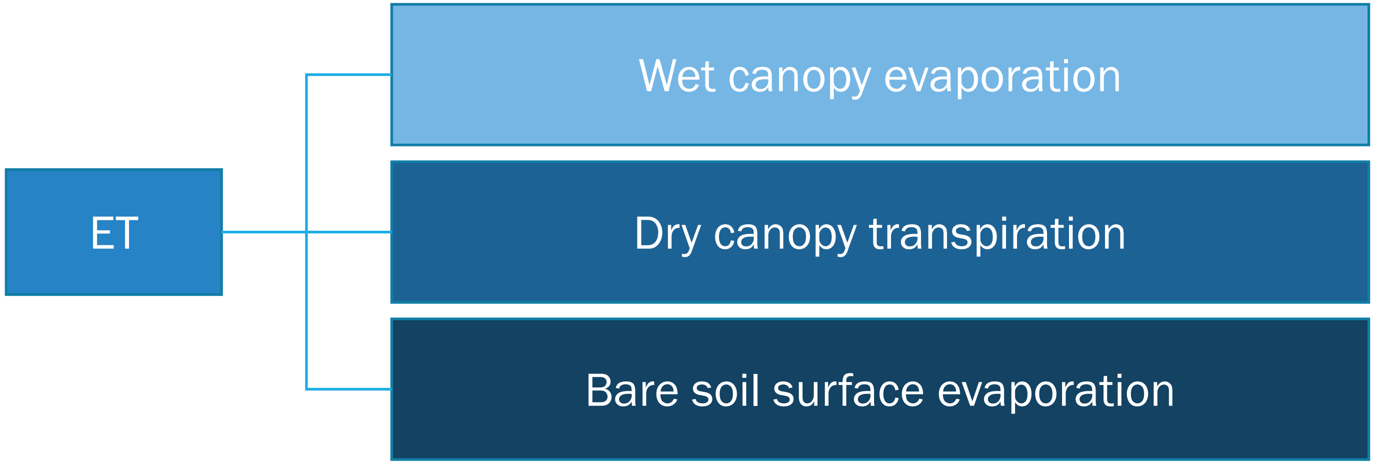


EVAPOTRANSPIRATION SIMULATION

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

$$E_p = \frac{s(R_n - G) + pc_p d_a / r_a}{s + \gamma(1 + r_s / r_a)}$$

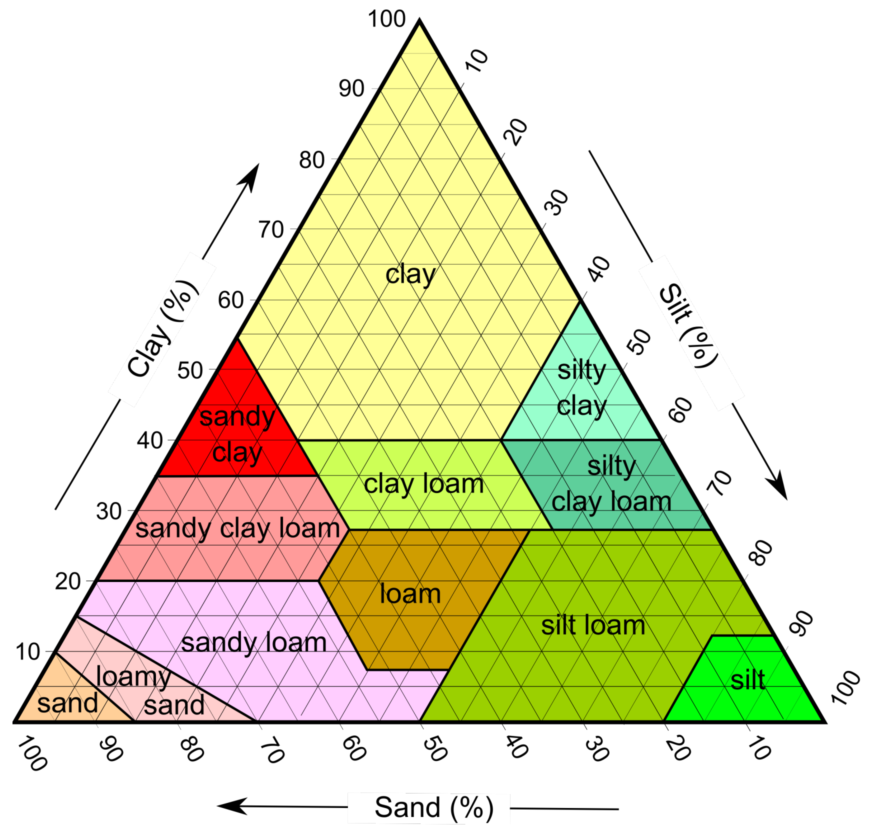
- Made up of three components for each elevation band and vegetation type



- 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
  - K_{sat}
  - Field capacity
  - Wilting point
  - Residual capacity
  - And other soil characteristics

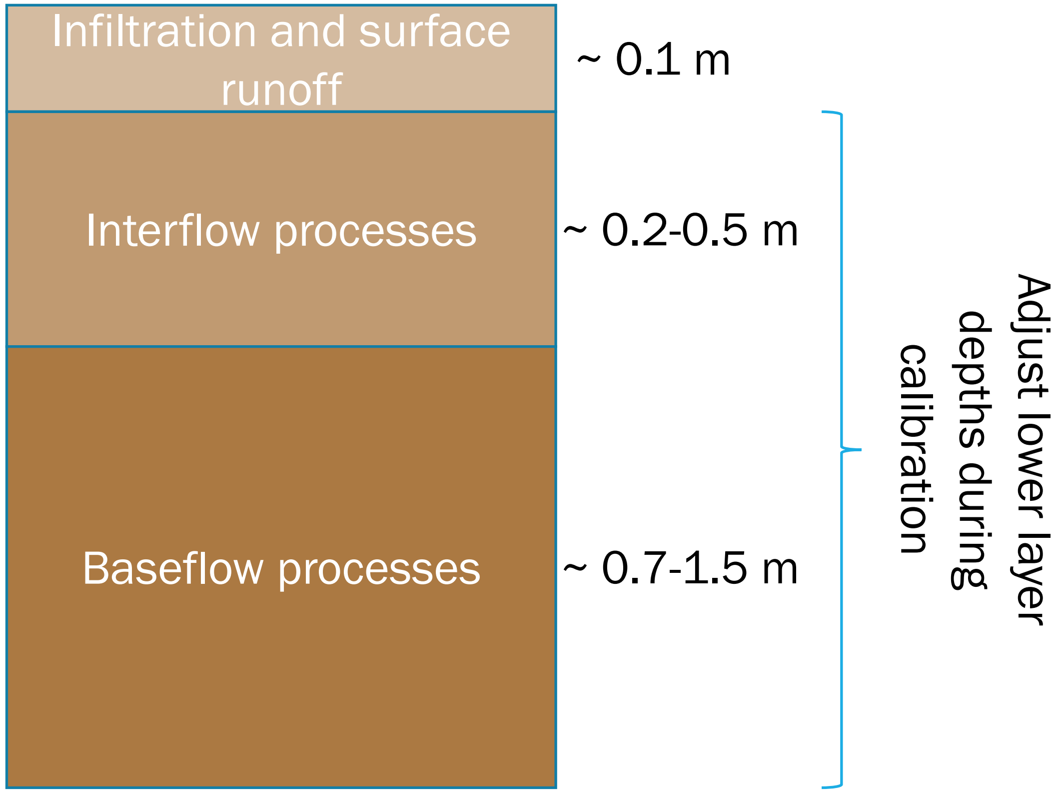


USDA Class	Soil Type	% Sand	% Clay	Bulk Density g/cm^3	Field Capacity cm^3/cm^3	Wilting Point cm^3/cm^3	Porosity fraction	Saturated Hydraulic Conductivity cm/hr
1	s	94.83	2.27	1.49	0.08	0.03	0.43	38.41
2	ls	85.23	6.53	1.52	0.15	0.06	0.42	10.87
3	sl	69.28	12.48	1.57	0.21	0.09	0.4	5.24
4	sil	19.28	17.11	1.42	0.32	0.12	0.46	3.96

Image in public domain:
https://commons.wikimedia.org/wiki/File:SoilTexture_USDA.png

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 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 meters)
  - GLDAS VIC 3 Layers (0-0.1, 0.1-1.6, and 1.6-1.9 meters)



- 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**

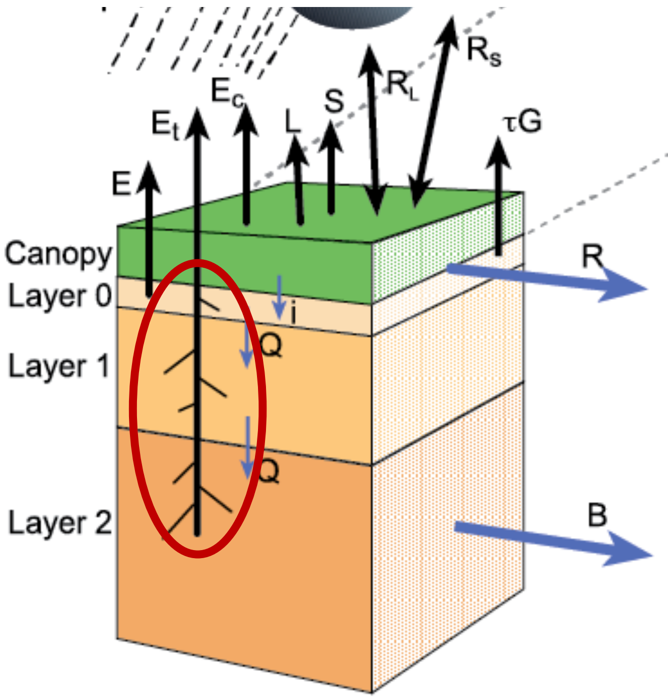


Image from Open Access VIC Documentation: http://vic.readthedocs.io/en/master/Overview/ModelOverview/

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

Yuting Yang[1], Randall J. Donohue[1,2], and Tim R. McVicar[1,2]

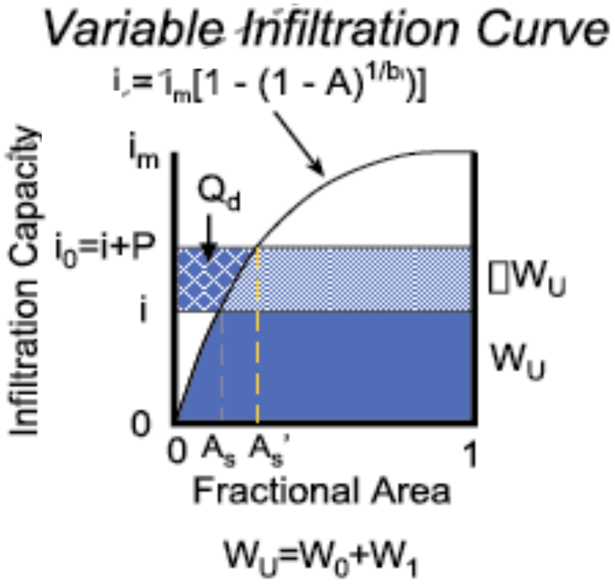
[1]CSIRO Land and Water, Canberra, Australia, [2]Australian Research Council Centre of Excellence for Climate System Science, Sydney, Australia

Abstract Plant rooting depth (Z_r) is a key parameter in hydrological and biogeochemical models, yet the global spatial distribution of Z_r is largely unknown due to the difficulties in its direct measurement. Additionally, Z_r observations are usually only representative of a single plant or several plants, which can differ greatly from the effective Z_r over a modeling unit (e.g., catchment or grid-box). Here, we provide a global

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 >0 - ~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)



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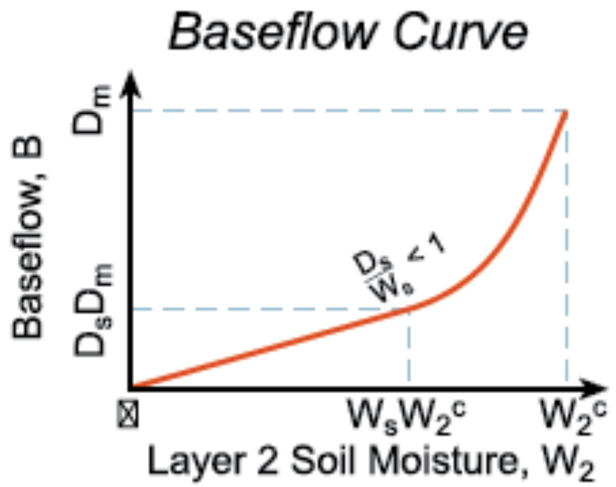
SOIL DRAINAGE

- 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: $B = \frac{D_s \cdot D_{smax}}{W_s W_n^c} \cdot W_n$



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http://vic.readthedocs.io/en/master/Overview/ModelOverview/

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 to for different results

A	B	C	D	E	F	G
Dsmax [mm]	Ds [-]	Ws [-]	Wnc [mm]	Qbase(t1) [mm day-1]	Qbase(t2) [mm day-1]	*ΔQbase [mm day-1]*
30	0.2	0.8	50	45	46.5	*1.5*
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	0.4	0.6	50	20	20.66666667	*0.6666666667*
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 * soildepth

STREAMFLOW ROUTING

- Streamflow routing performed after LSM scheme simulations
- Developed **specifically to be coupled with LSM** [*Lohmann et al.*, 1996; 1998]
- Grid-based routing scheme based on the **unit hydrograph approach**
- Solves lumped linearized time-invariant Saint-Venant equations to create the **Impulse Response Functions (IRF) for each grid**

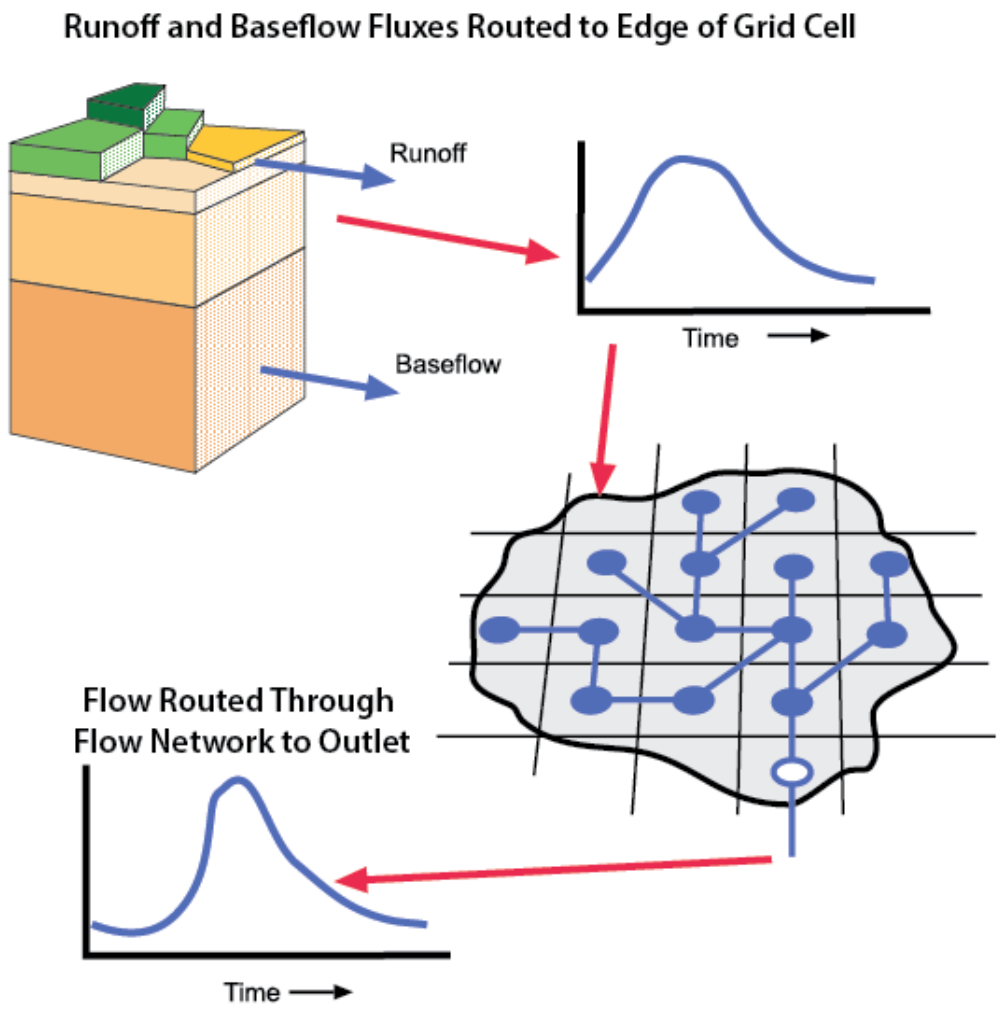

Image from Open Access VIC Documentation:
http://vic.readthedocs.io/en/master/Overview/ModelOverview/

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 **UNIX/LINUX operating systems**
  - Possible to run using Windows OS but not supported
- Simulations usually use about 5 MB of RAM
  - Usage does not increase with basin size!
- **Need considerable amount of storage** for I/O data
  - Dependent on basin size, time step, etc.

VIC RESOURCES

- Old VIC website: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml
- **Current VIC website:** http://vic.readthedocs.io/en/master/
- **Routing model website:** http://rvic.readthedocs.io/en/latest/
- VIC GitHub: https://github.com/UW-Hydro/VIC
- RVIC GitHub: https://github.com/UW-Hydro/RVIC/

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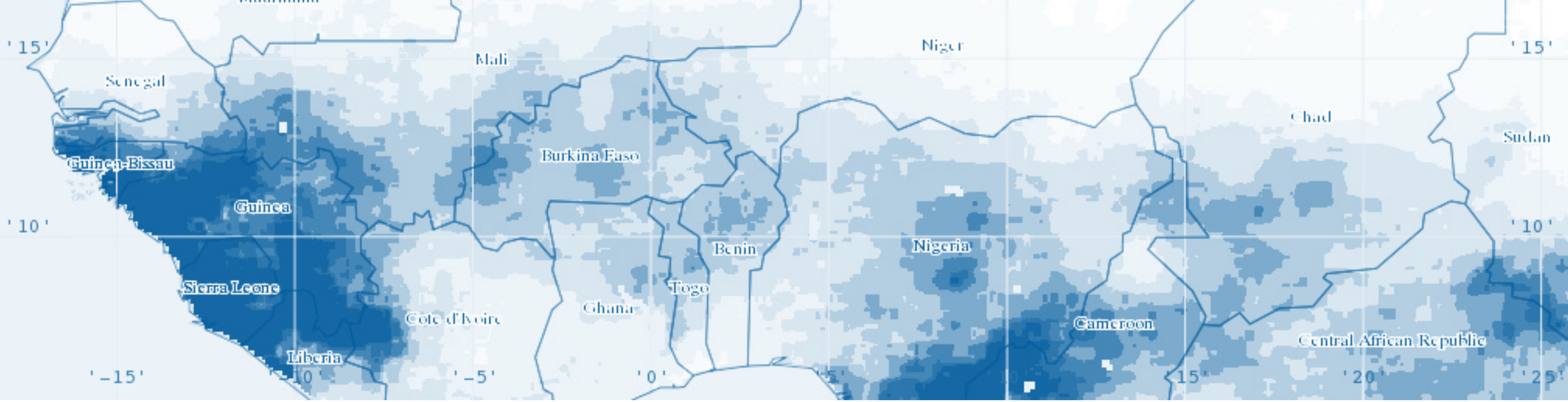

BREAK

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VIC/BCSPP Training
Huntsville, AL

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