Calibrating and Re-Calibrating a Global Vegetation Model

Thomas G. Dietterich

Eric Chown

MAPSS (Neilson, 1995)

Global Climate Model → predicted climate → MAPSS → predicted vegetation

- Predictions
  - – LAI in each pixel (LAI_{tree}, LAI_{grass}, LAI_{shrub})
  - – Classification into one of 74 possible biomes
    - tall grass prarie, desert, conifer forest, etc.

MAPSS (2)

- Optimization model:
  - find LAI values that achieve “water balance” and “light balance”
- Water Balance
  - (soil water in – soil water out) = 0 over 12 months
  - soil water always ≥ 0
- Light Balance
  - amount of light reaching forest floor matches grass LAI

Hydrology Model

- Rainfall-Snowfall
  - canopy interception and through-fall
  - snow accumulation and melt
  - separate modeling of saturated and unsaturated soil water flow
  - separate modeling of deep, medium, and shallow soil water pools
  - transpiration from shallow soil for grasses and shrubs, from shallow and medium for trees
- Each 10x10km cell is independent (no lateral flows)

Calibration

- MAPSS is an aggregate model
- Transpiration and soil water flow equations chosen empirically
  - $\alpha e^{\beta X}$
  - must set two parameters in each equation
- Criteria
  - correctly predict boundaries of major biomes
  - correctly predict seasonality of water flows
  - correctly predict observed LAI
    - 22 quantitative sites; overall qualitative behavior

Manual Calibration

- Calibrate grass transpiration parameters and unsaturated deep and middle water parameters
  - use data from praries, where trees and shrubs are absent and there is no saturated water flow
- Calibrate tree transpiration parameters
  - forests with unsaturated soil only
  - separately for different climate zones
- Calibrate shrub transpiration parameters
  - shrub savanah with unsaturated soil
- Calibrate top layer saturated water flow
  - shrublands where middle and deep water flow are “lost”
- Calibrate deep saturated water flow
  - grasslands where middle flow can be ignored
- Calibrate middle saturated water flow
  - grasslands where all flows occur

Automated Re-Calibration

- Goal: Determine how stable the model parameterization is
- Method:
  - Use calibrated model (known parameter values) to generate predicted LAI values over USA
  - Apply optimization algorithm to see if we can recover these parameter values

Automated Calibration

- Define error measure

$$J(\ominus) = \begin{array}{l} (\widehat{LAI}_{tree} - LAI_{tree})^2 + \\ (\widehat{LAI}_{grass} - LAI_{grass})^2 + \\ (\widehat{LAI}_{shrub} - LAI_{shrub})^2 + \\ (\widehat{RUNOFF} - RUNOFF)^2 \end{array}$$

- Search for Θ to minimize J

Global Optimization Algorithms

- Non-gradient search (Powell's method)
- Gradient search (conjugate gradient)
- Simulated Annealing

- All FAIL on this problem!
  - nonlinearlities and complex interactions

Automated Model Decomposition

- Identify parameter subsets that can be calibrated independently (sequentially)
- Identify sites that we are confident correspond to those parameter subsets
- Apply simulated annealing to parameter subsets

Method

- Automated program analysis to identify paths through the simulation that only involve small numbers of parameters
- Empirical method of identifying data points that belong to a path (with high probability)
- Optimization of parameter subsets

Transpiration Parameter Results

Iteration	Grass	Tree1	Tree2	Tree3	Shrubs	SlopeG	SlopeT	SlopeS
1	4.265					3.792		
2	4.249	3.748				1.417	1.001	
3	4.259		3.502			4.999	1.003	
4	4.278			2.750		3.496	1.032	
5	4.252				9.254	2.248		3.002
6					9.246			3.002
7	4.249					1.998		
8	4.251					2.072		
Target	4.250	3.750	3.500	2.750	9.275	2.000	1.000	3.000
Range	2 – 8.5	1.5 – 5	1.5 – 5	1.5 – 5	1.2 – 4	4 – 15	0 – 5	0 – 5

Soil Water Flow Results

	Unsaturated						Saturated					
Iter	Deep1	Deep2	Mid1	Mid2	Top1	Top2	Deep1	Deep2	Mid1	Mid2	Top1	Top2
1	0.786	11.476	0.286	2.744								
2	0.704	11.607	0.125	2.337								
3	0.194	9.971	0.491	2.994								
4	0.443	10.934	0.597	2.939								
5	0.371	10.293	0.640	5.051								
6	0.443	10.933	0.604	2.944	0.834	2.530						
7	0.274	9.754	0.603	3.644			0.849	11.447				
8	0.201	9.982	0.504	3.003			0.857	10.128	0.816	3.087	0.613	0.719
Target	0.200	10.000	0.500	3.000	0.800	2.500	0.800	10.000	0.800	3.000	0.500	1.000
Range	0 – 1	1 – 20	0 – 1	1 – 7.5	0 – 1	1 – 7.5	0 – 1	1 – 20	0 – 1	1 – 5	0 – 1	0.5 – 3

Lessons Learned

- Data is too sparse to support fully-automated calibration
- Complex models cannot be calibrated simply by wrapping a clever optimization algorithm around the system (black box optimization)
- Automated re-calibration is possible, but requires a divide-and-conquer strategy
- Associating data with paths through a complex model can be automated
- Calibration of model subcomponents is possible, but requires extensive hand-tweaking of optimization parameters
- MAPSS calibration is stable except for middle layer saturated flow parameters, which are under-constrained.