Calibration and Comparison of Forest Canopy Interception Models

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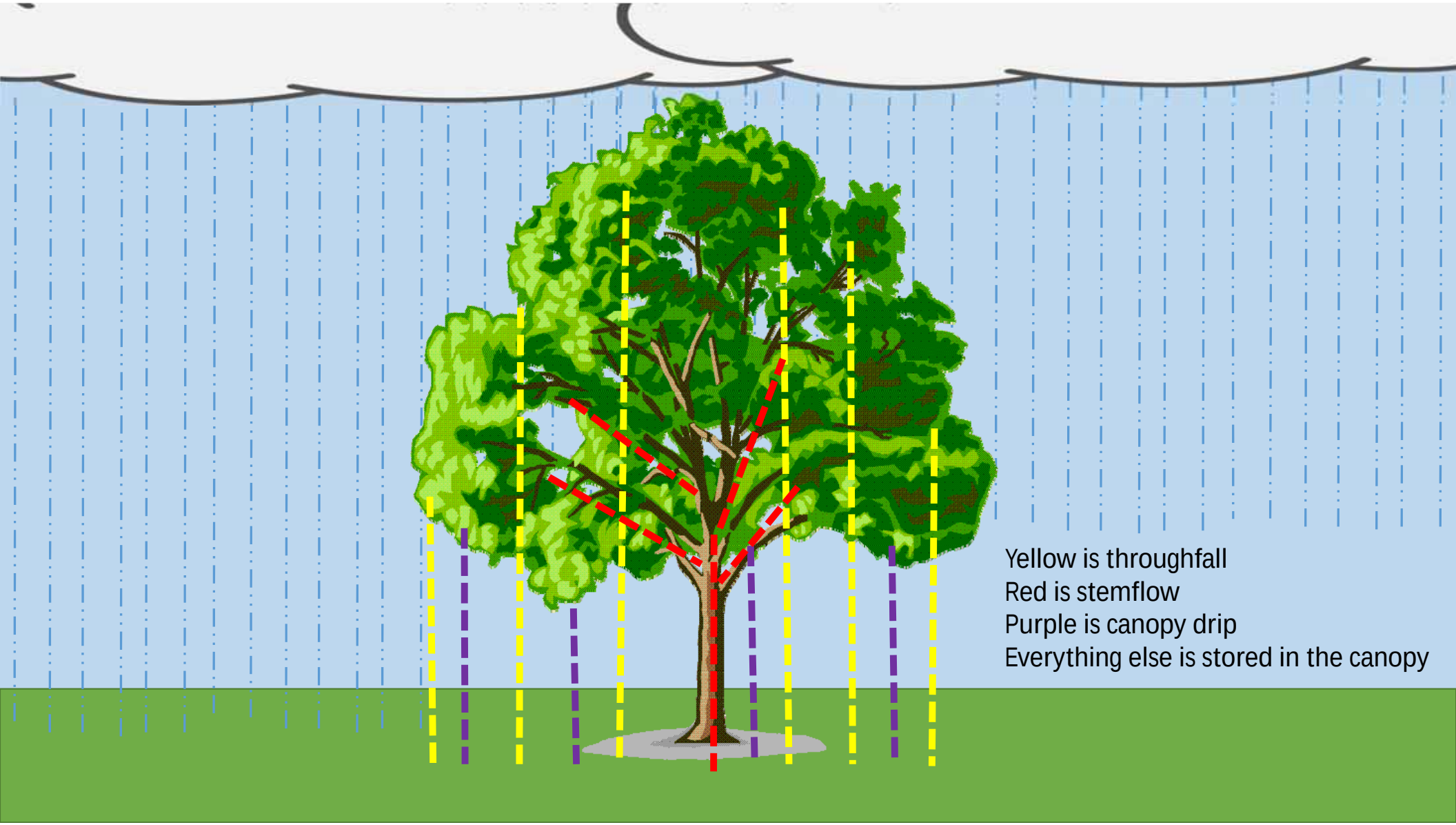

Yellow is throughfall
Red is stemflow
Purple is canopy drip
Everything else is stored in the canopy

Background

- Interception by the canopy is an important component of the hydrologic cycle.
  - Can account for up to 50% of total rainfall.
  - In Mississippi: 20% of total rainfall.
  - If we get 50 inches of rain a year here, 10 inches of rainfall never reach the ground.
- It is important to accurately simulate interception to simulate river flow using rainfall/runoff models
  - These models are often run on daily timesteps

wikipedia.org/wiki/Interception_(water)

Models of canopy interception

- Empirical model
  - Curve number: 20% of total rainfall (initial abstraction)
- Physically based models (developed for monthly timesteps)
  - Rutter style models
    - Rutter sparse
  - Gash style models
    - Gash sparse
    - Liu
- Evapotranspiration from the canopy is from Penman-Montieth

Gash model

- Interception

$$\sum_{j=1}^{n+m} I_j = n(1-p-p_t)P_G^{`} + \frac{\overline{E_P}}{\overline{R}} \sum_{j=1}^{n} \left(P_{G,j} - P_G^{`}\right) + (1-p-p_t) \sum_{j=1}^{m} P_{G,j} + qS_t + p_t \sum_{j=1}^{m+n-q} P_{G,j}$$

- Rainfall necessary to saturate the canopy

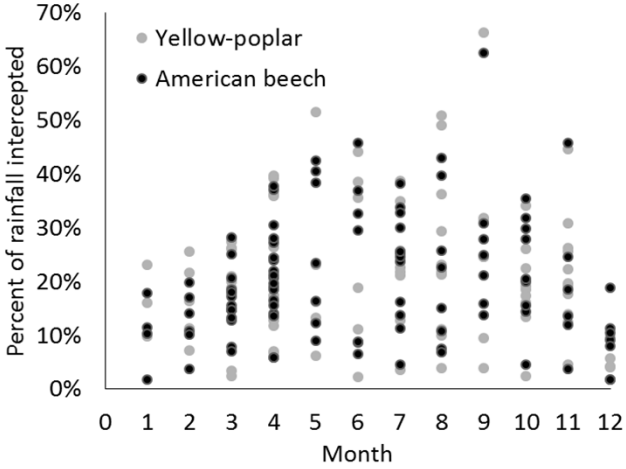
$$P_G^{`} = -\frac{\overline{R}S}{\overline{E_P}} ln\left[1 - \frac{\overline{E_P}}{(1-p-p_t)\overline{R}}\right]$$

Objective

- Conduct an automatic calibration on five rainfall interception models
  - Rutter (Rutter 1975)
  - Rutter Sparse
  - Gash (1979)
  - Gash Sparse (Gash et al. 1995)
  - Liu (Liu 1997)
- The results will
  - Assess how the models perform
  - Identify the best model
  - Compare the best fit values for inputs across the 5 models

Study site

- Fair Hill Natural Resources Management Area in Maryland
- Humid maritime climate with well-defined seasons
- Mean 30-year total annual precipitation is approximately 1200 mm
- The forest canopy is comprised of yellow-poplar and American beech
- Data collected during leaf and leafless periods



Automatic calibration

- PEST: Parameter Estimation and Uncertainty Analysis
- Nonlinear parameter estimator
- Employs the Gauss–Marquardt–Levenberg method to find the optimal parameter set to minimize the sum of the square errors between measured and modeled data
- Advantages over similar parameter optimization software.
  - model independent
  - free and open-source
  - well documented
  - frequently referenced in the literature.

Automatic calibration

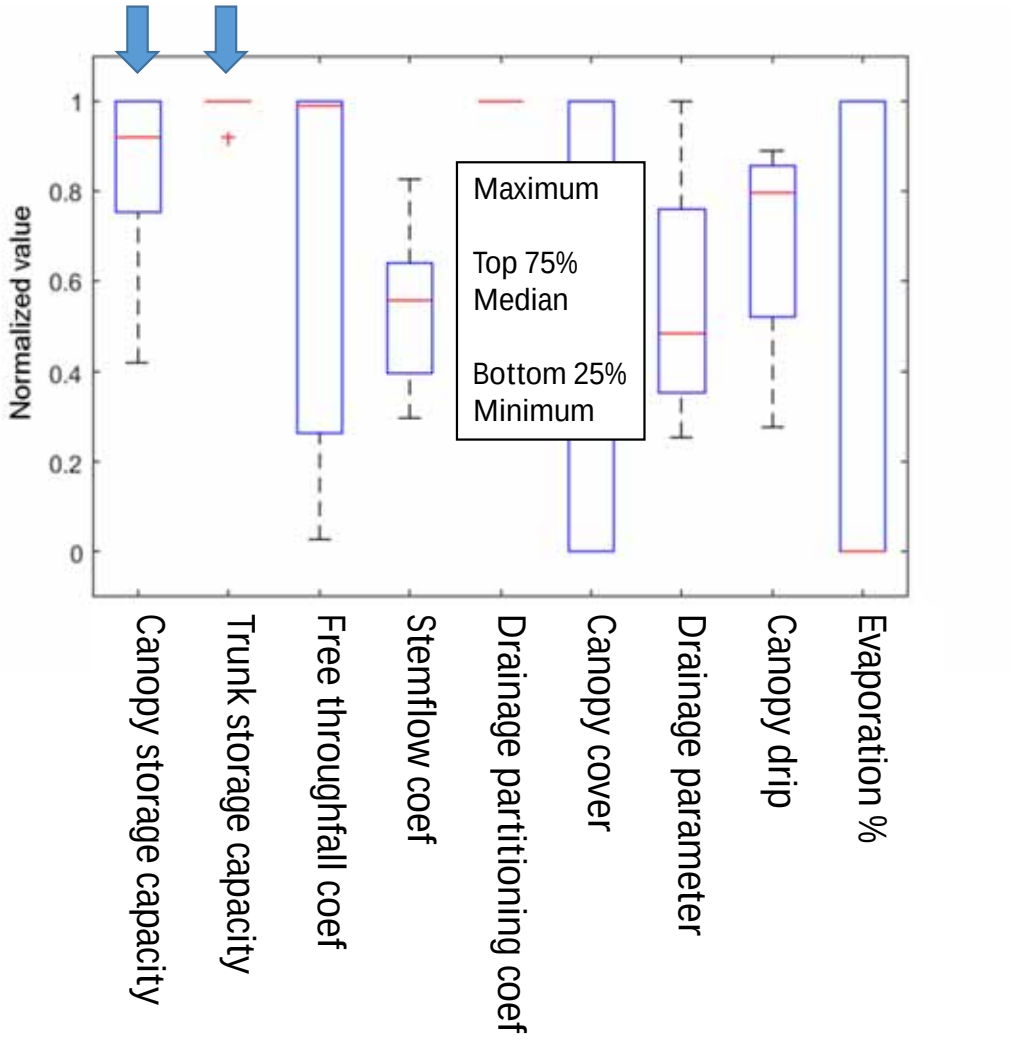
- 4 calibrations for each of the 5 models = 20 total calibrations
  - Rutter, Rutter Sparse, Gash, Gash Sparse, Liu
  - leaf and unleafed
  - American beech and yellow poplar
- The calibration process provided no prior information regarding leafed versus leafless conditions, or for American beech versus yellow-poplar stands
- The only differences were the field-observed values of interception.
  - leaf and unleafed
  - American beech and yellow poplar

Parameter ranges

Abb.	Parameter Description	R	RS	G	GS	L	Parameter PDF
S	canopy storage capacity (mm)	X	X	X	X	X	$U(0.29, 2.24)$
S_t	trunk storage capacity (mm)	X	X	X	X	X	$U(0.0037, 0.9800)$
p	free throughfall coefficient (%)	X		X		X	$U(0.06, 0.55)$
p_t	stemflow coefficient (%)	X		X	X		$U(0.0031, 0.0600)$
p_d	drainage partitioning coefficient (%)		X				$U(0.0076, 0.0324)$
c	canopy cover (unit area)		X		X		$U(0.43, 0.95)$
b	empirical drainage parameter (mm)	X					$U(3.0, 4.6)$
D_S	canopy drip when $C = S$ (mm hr^{-1})	X					$U(0.024, 0.740)$
ϵ	trunk / canopy evaporation (%)	X	X				$U(0.022, 0.024)$

Results: calibrated parameter values

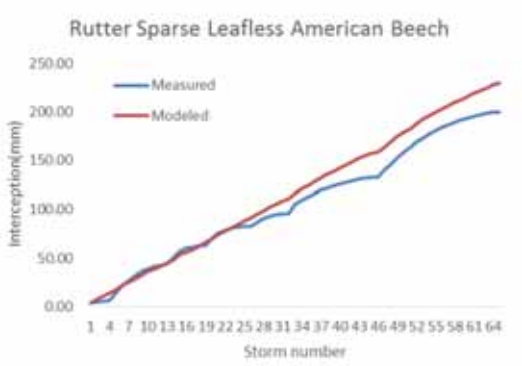
In a sensitivity analysis of these models the most important inputs were
canopy storage capacity
trunk storage capacity
canopy cover

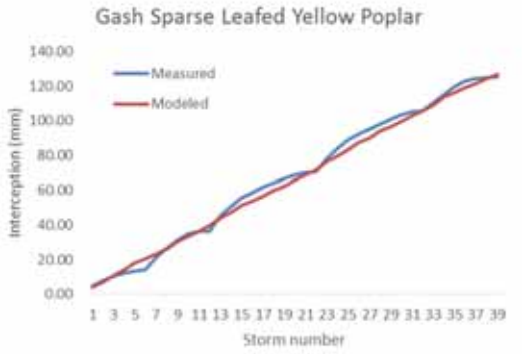


Results: cumulative error of measured vs modeled interception

	American beech		Yellow-poplar	
	Leafed	Leafless	Leafed	Leafless
Gash	1.8% (2.4)	4.1% (8.1)	-1.2% (-1.6)	-2.5% (-4.7)
Gash Sparse	0.8% (1.1)	-0.3% (-0.6)	-1.2% (-1.5)	-0.3% (-0.6)
Rutter	-5.7% (-7.5)	-5.3% (-10.6)	-1.3% (-1.6)	0.0% (-0.1)
Rutter Sparse	-8.2% (-10.6)	-14.9% (-29.7)	-5.8% (-7.3)	-7.1% (-13.2)
Liu	9.1% (-11.9)	-1.8% (-3.6)	6.9% (-8.7)	-1.5% (-2.8)

Percent error and absolute error (mm) of measured versus modeled cumulative interception. Absolute error (mm) is given in parenthesis





Results: error between measured and modeled individual storm events

	American beech		Yellow-poplar	
	Leafed	Leafless	Leafed	Leafless
Gash	0.39	0.44	0.25	0.48
Gash Sparse	0.29	0.40	0.21	0.44
Rutter	0.34	0.44	0.37	0.46
Rutter Sparse	0.36	0.45	0.23	0.48
Liu	0.41	0.48	0.28	0.46

Coefficient of determination (R^2) for measured versus modeled interception for individual rainfall events.

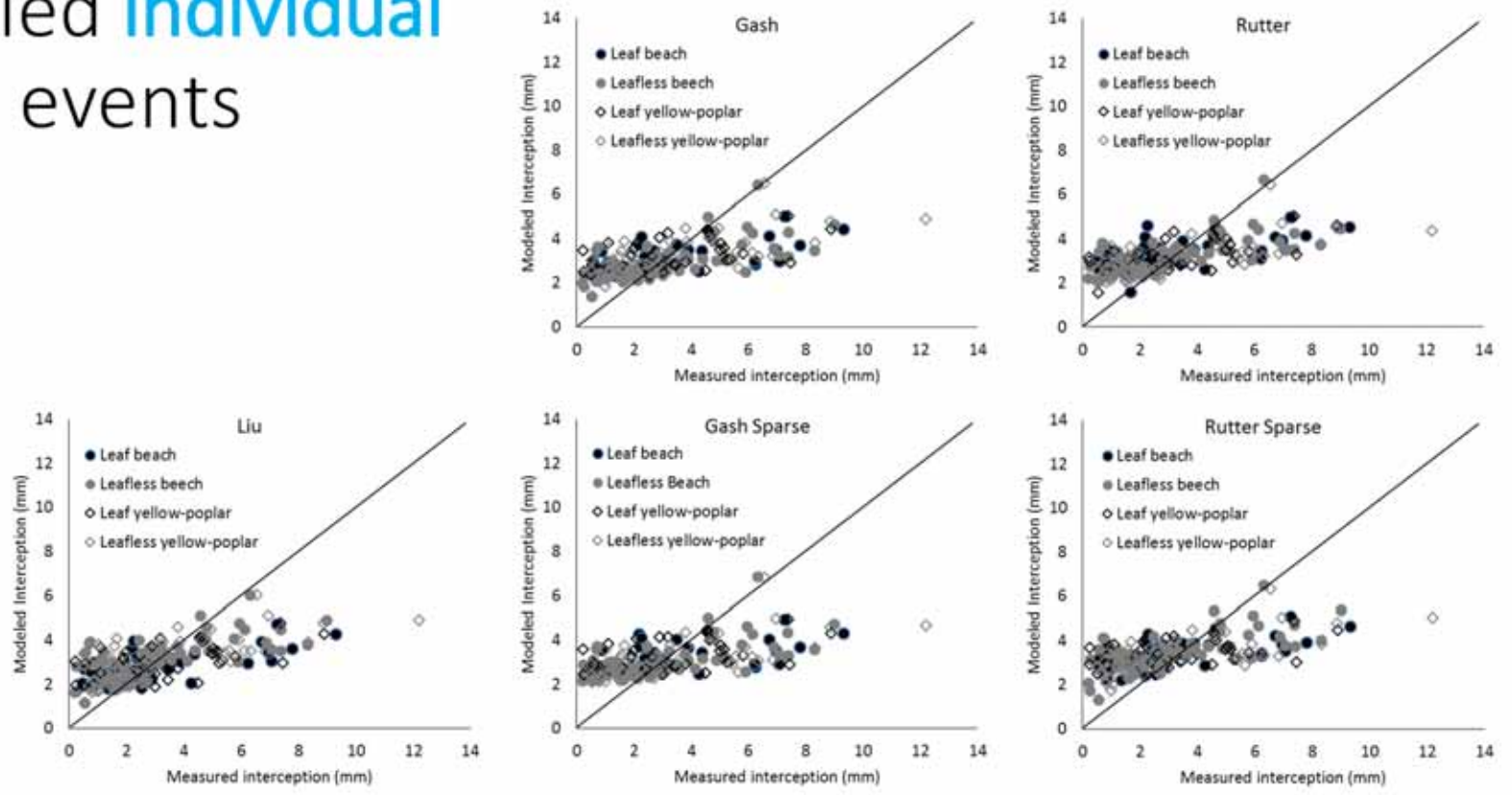
	American beech		Yellow-poplar	
	Leafed	Leafless	Leafed	Leafless
Gash	1.9	1.7	1.8	1.9
Gash Sparse	2.0	1.8	1.9	1.9
Rutter	2.0	1.8	1.8	1.9
Rutter Sparse	2.0	1.8	1.9	1.9
Liu	1.9	1.7	1.8	1.8

Root mean squared error between measured versus modeled interception for individual rainfall events.

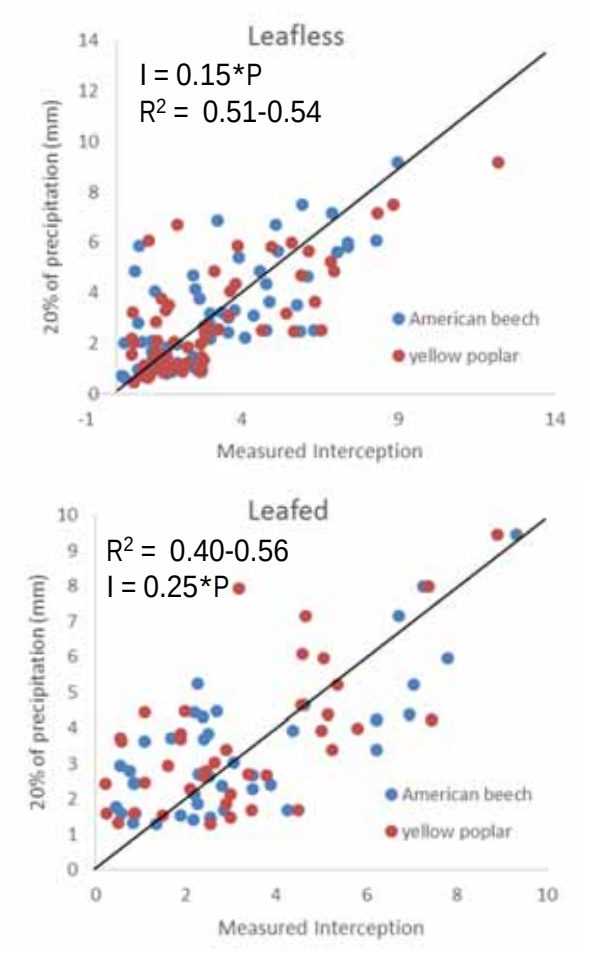
Note that:

- Average rainfall = 3.1 mm
- Min rainfall = 0.2
- Max rainfall = 12.2
- Standard deviation = 2.2

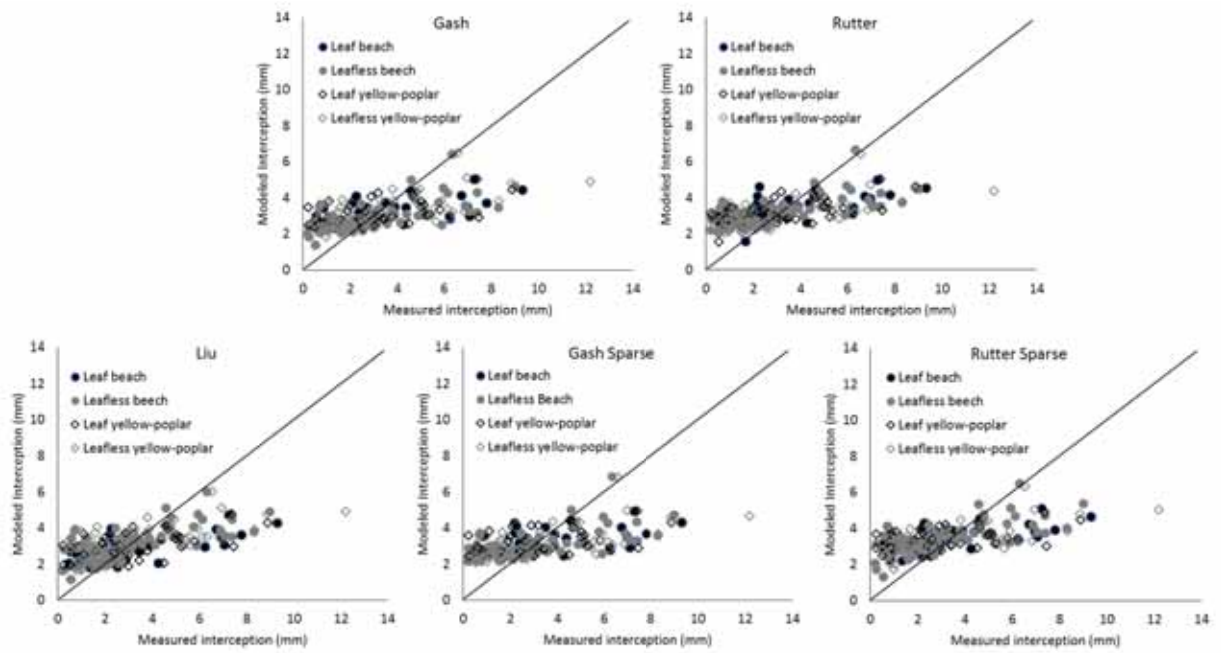
Results: error between measured and modeled individual storm events



Interception as 20% of rainfall (curve number) for leaf and leafless conditions



Modeled interception



Conclusion

- All the models behave somewhat similarly
- The models are not as dynamic as the measured system
  - They cannot simulate low or high levels of interception
  - There is more storage in the actual system than in the modeled system
    - Model parameters
      - maximum ET = 5.07 mm
      - maximum canopy storage = 2.24 mm,
      - maximum trunk storage (St) = 0.98 mm.
    - Given these ranges simulated interception could not exceed 8.29 mm but measured interception was as high as 12 mm.
      - (does not accounting for free throughfall, stemflow, drainage partitioning, or canopy drip).

Conclusion

- These interception models were originally designed to be run as cumulative models on a monthly timestep. Based on their behavior, they should not be used on a daily timestep.
- Until we develop a better model, we should continue to represent interception as a percentage of rainfall in models with daily timesteps


Thank you!