Groundwater impacts on soil moisture simulation

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Problems due to free drainage

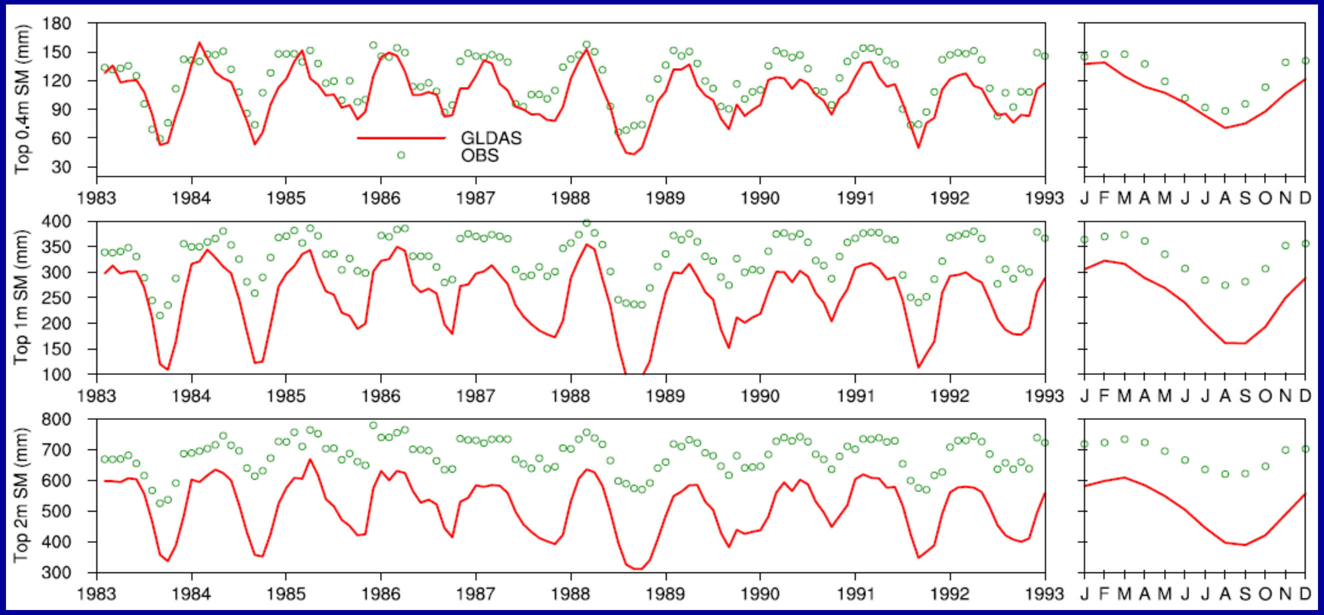
Total soil water storage: $ds/dt = P - E - R$

1. **Upper-boundary condition ($P - E - R_{sur}$)**
2. **Lower-boundary condition (R_{sub})**

Redistribution among layers:

1. **Soil hydraulic properties (K_{sat}, ψ_{sat})**
2. **Vertical distribution of roots**

Problems due to free drainage (GLDAS/Noah)

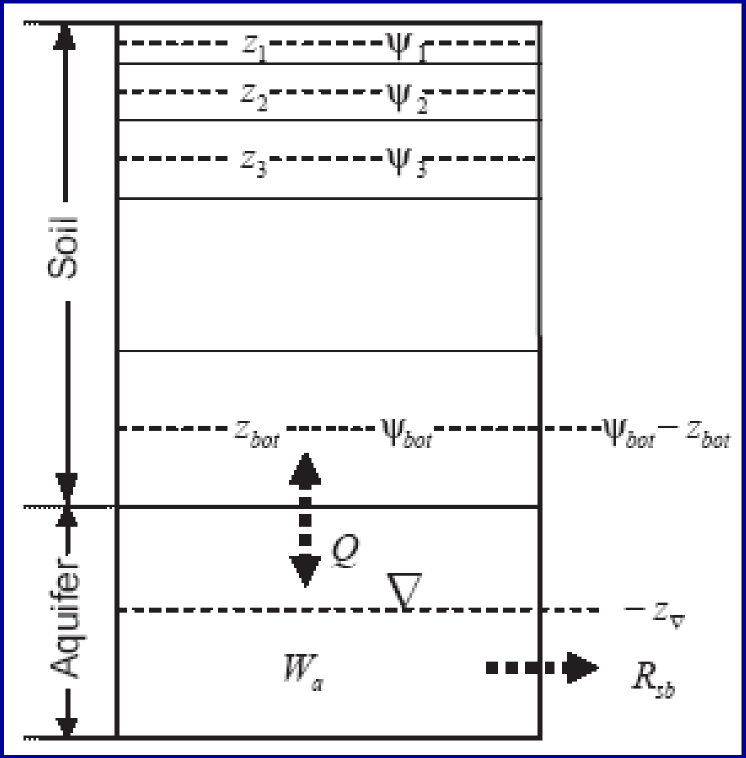


Top 0.4m

Top 1.0m

Top 2.0m

A simple groundwater model (SIMGM) (Niu et al., 2007)



Water storage in an unconfined aquifer:

$$\frac{dW_a}{dt} = Q - R_{sb}$$

$$z_\nabla = W_a / S_y$$

Recharge Rate:

$$Q = -K_a \frac{-z_\nabla - (\psi_{bot} - z_{bot})}{z_\nabla - z_{bot}}$$

$$= K_a \left(1 + \frac{\psi_{bot}}{z_\nabla - z_{bot}}\right)$$

Problems when applied to CLM: too wet soil, possibly due to

- **Too small recharge rate from soil to aquifer (too small K_a);**
- **Too strong upward flow (too large soil suction, ψ_{bot});**
- **Too small groundwater discharge inducing overflow of groundwater to soil**

Modifications to SIMGM

Enlarge hydraulic conductivity K_a

K_{bot} (1 – exp(–f(z_{wt} –z_{bot})) / (f(z_{wt} –z_{bot})) → K_{bot}

Enlarge R_{sbmax} by e^2 = 7.39 (for Noah)

groundwater discharge rate:

$R_{sb} = R_{sbmax} * \exp(-f * z_{wt})$

→ $R_{sb} = R_{sbmax} * \exp(-f * (z_{wt} - z_{bot}))$

surface runoff rate:

$R_{sf} = P * F_{max} \exp(-0.5 * f * z_{wt})$

→ $R_{sf} = P * F_{max} \exp(-0.5 * f * (z_{wt} - z_{bot}))$

$$= K_a \left(1 + \frac{C_{mic}\,\psi_{bot}}{z_{\nabla} - z_{bot}}\right)$$

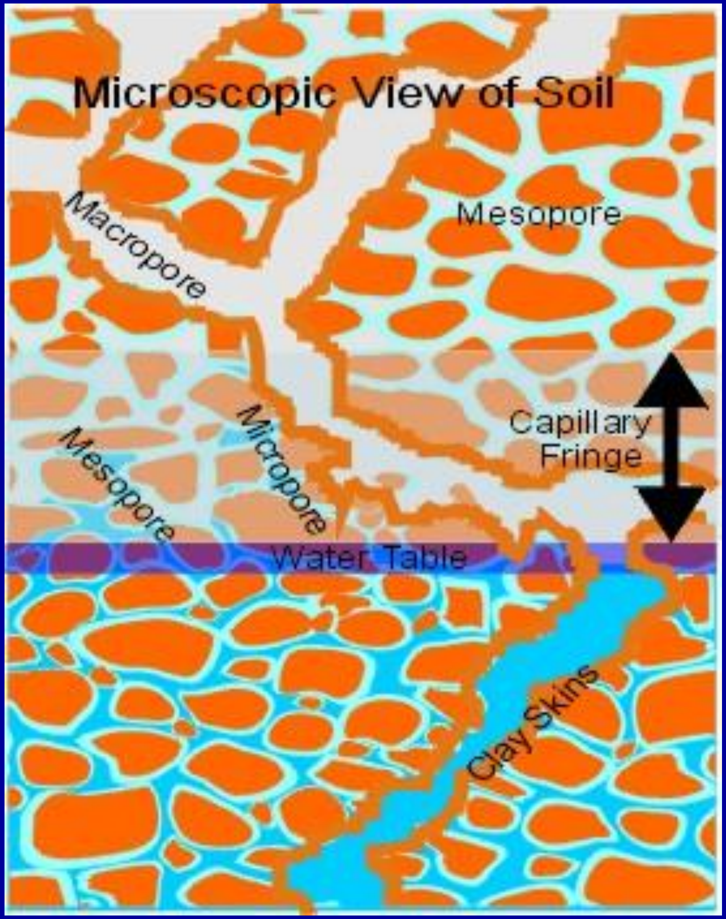
Limit upward flow:

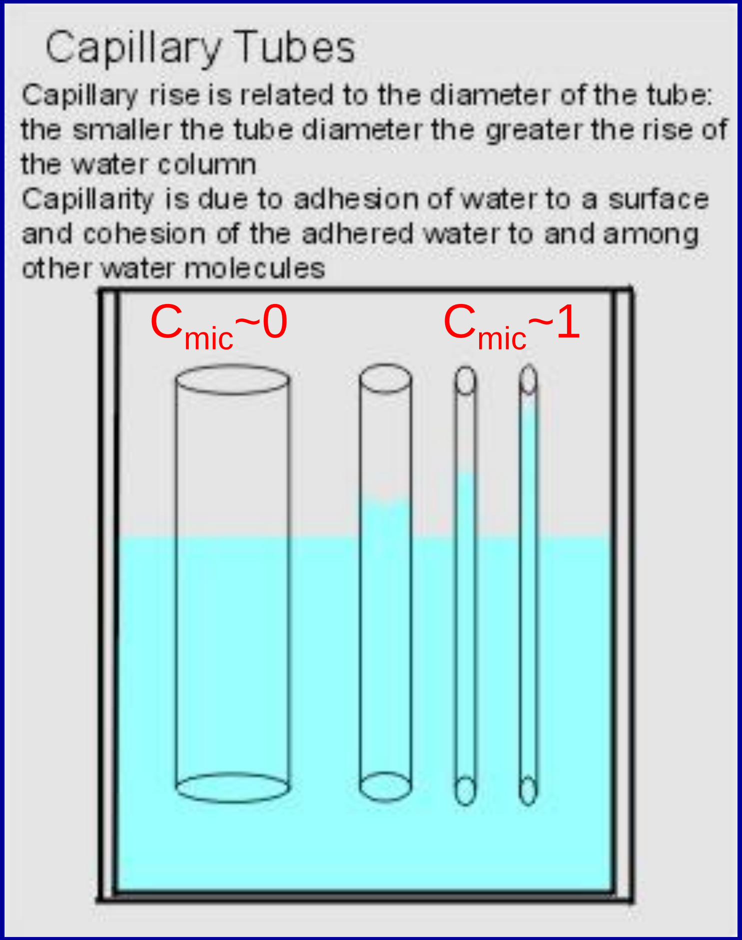
$C_{mic} * \psi_{bot}$ C_{mic} → fraction of micropore content

0.0 – 1.0 (0.0 ~ free drainage)

Capillary Fringe and Soil Pore-Size Distribution

See http://www.earthdrx.org/poresizegwflow.html



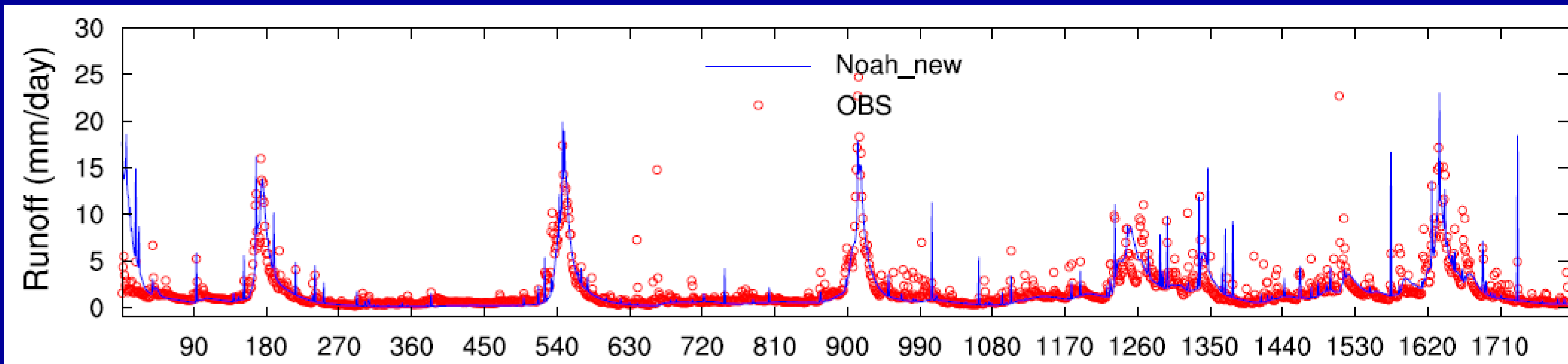


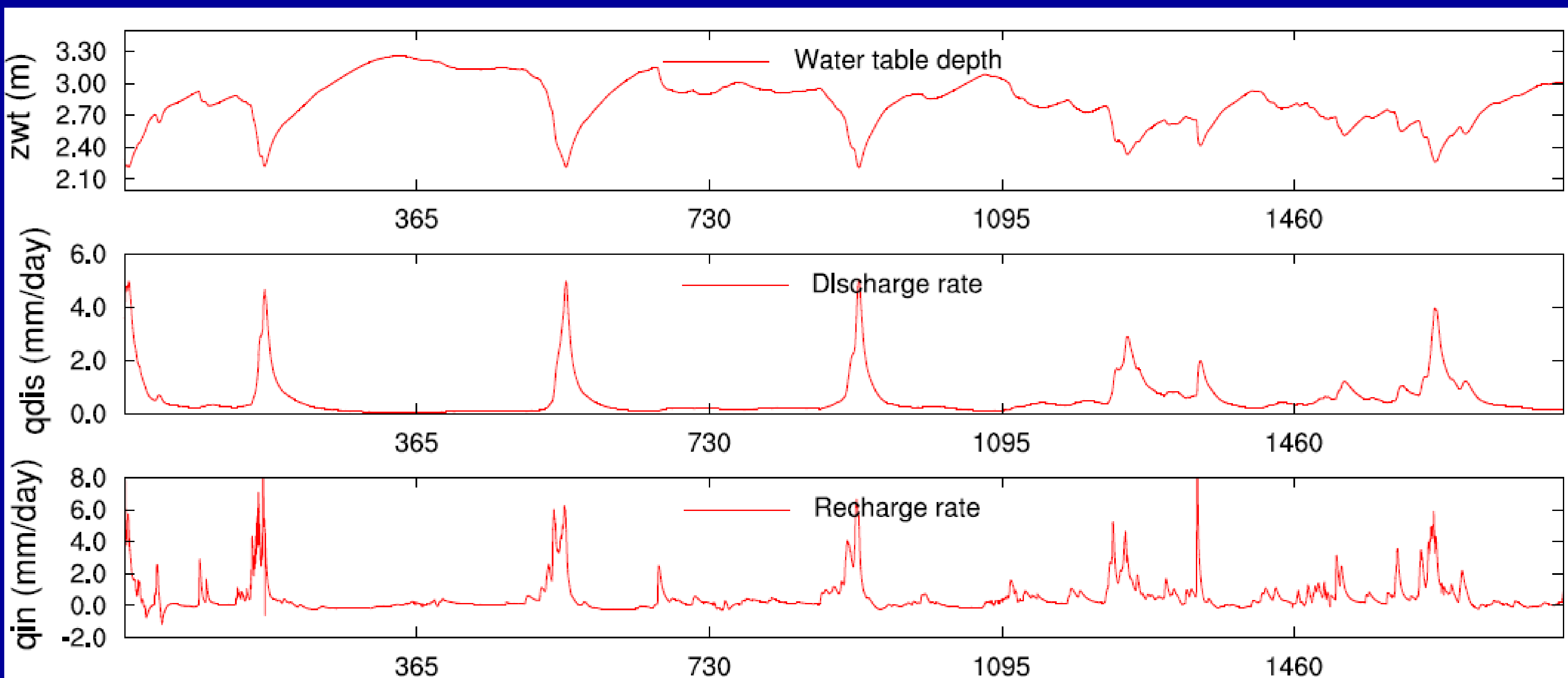
Macropore effects:

1. Larger recharge rate (through macropores)

2. Smaller upward flow (through micropores)

Tests against Sleepers River streamflow data





Soil moisture simulations in Illinois

Noah LSM with Noah schemes:

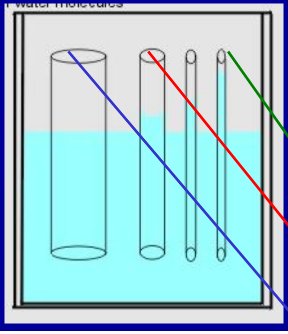
Stomatal resistance: Jarvis type

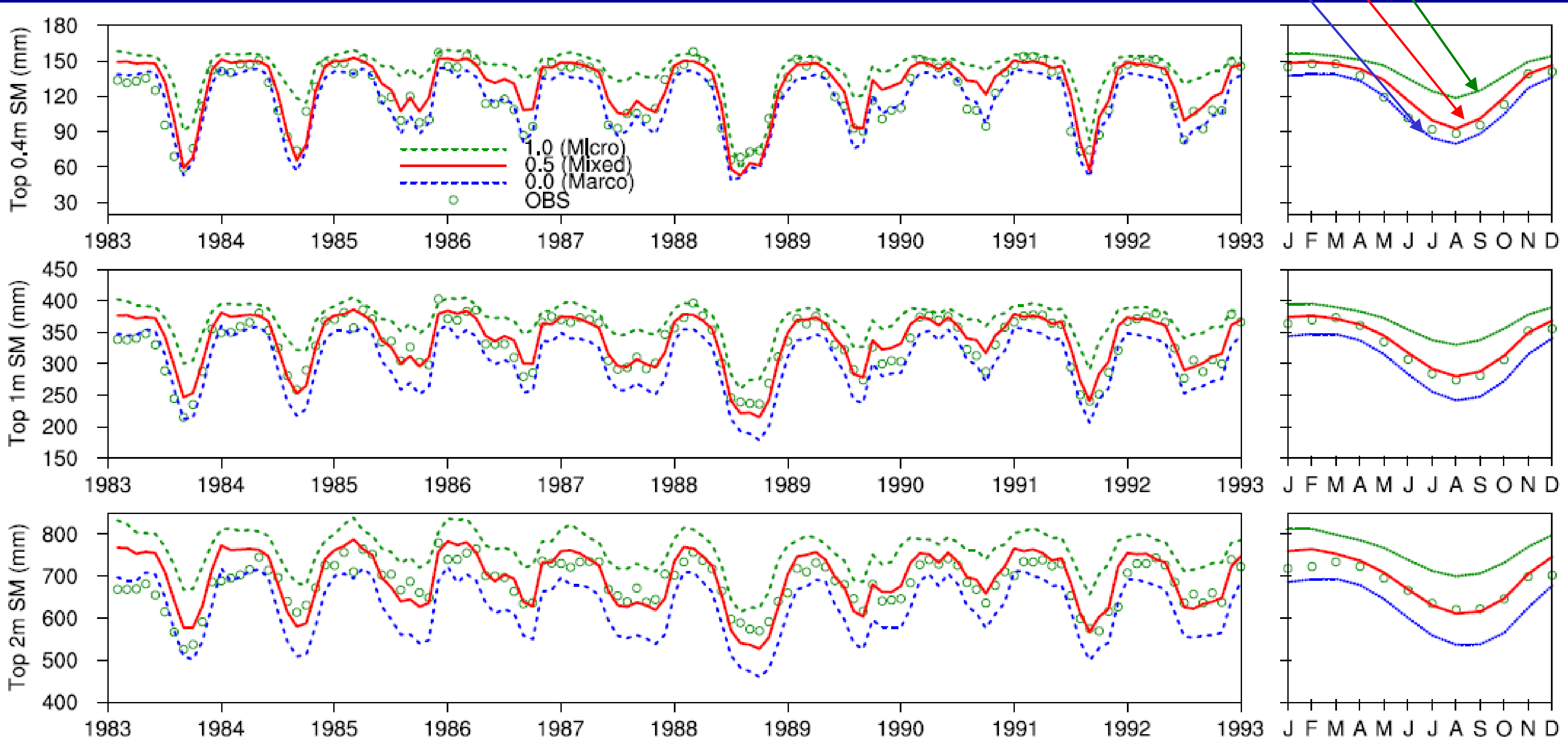
Soil moisture stress factor : soil moisture

Root distribution: 0.0 – 0.4m 85%;

0.4 – 1.0m 15%

Micropore fraction: C_{mic} = 0.5

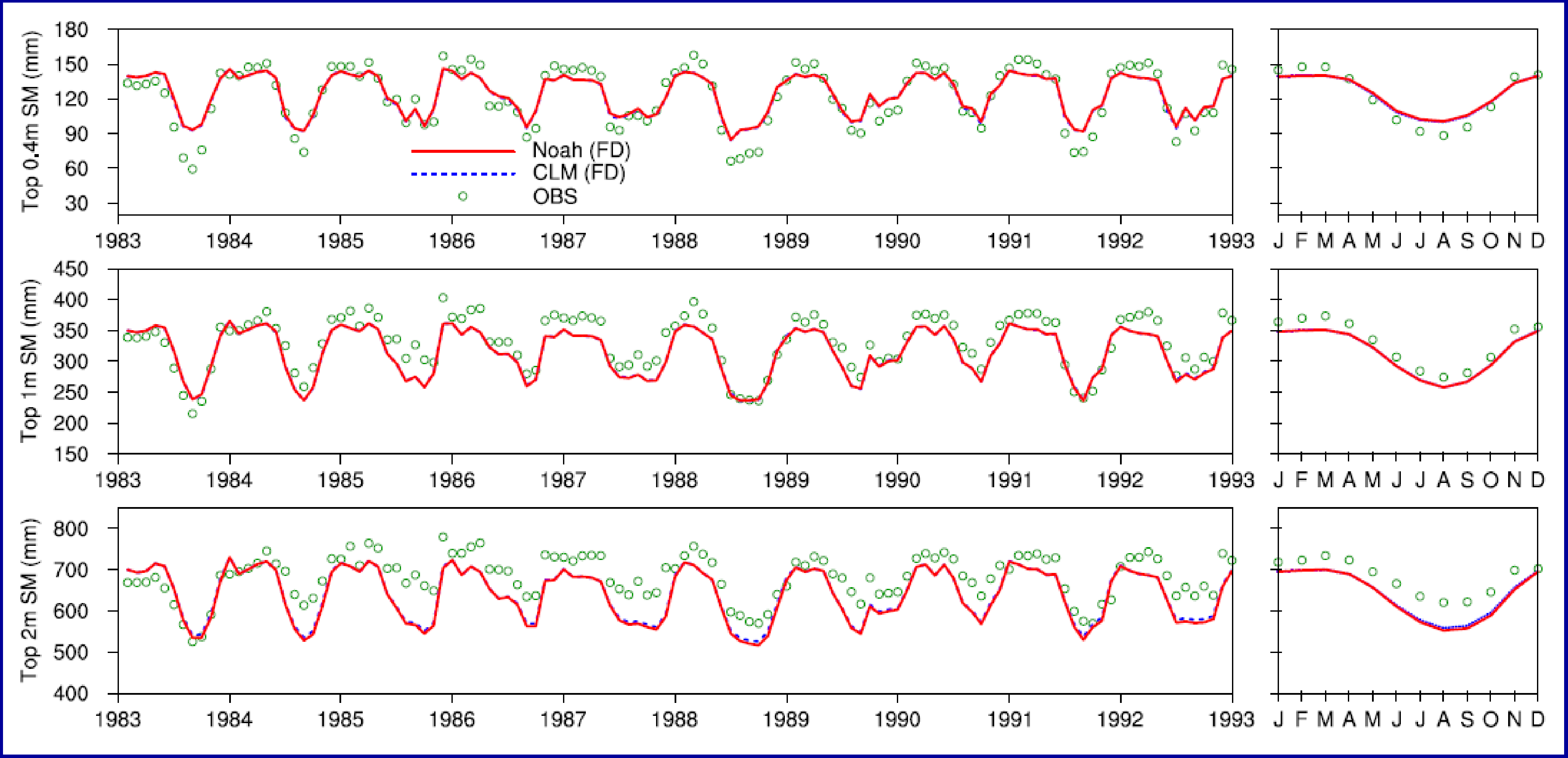




Noah LSM with CLM schemes

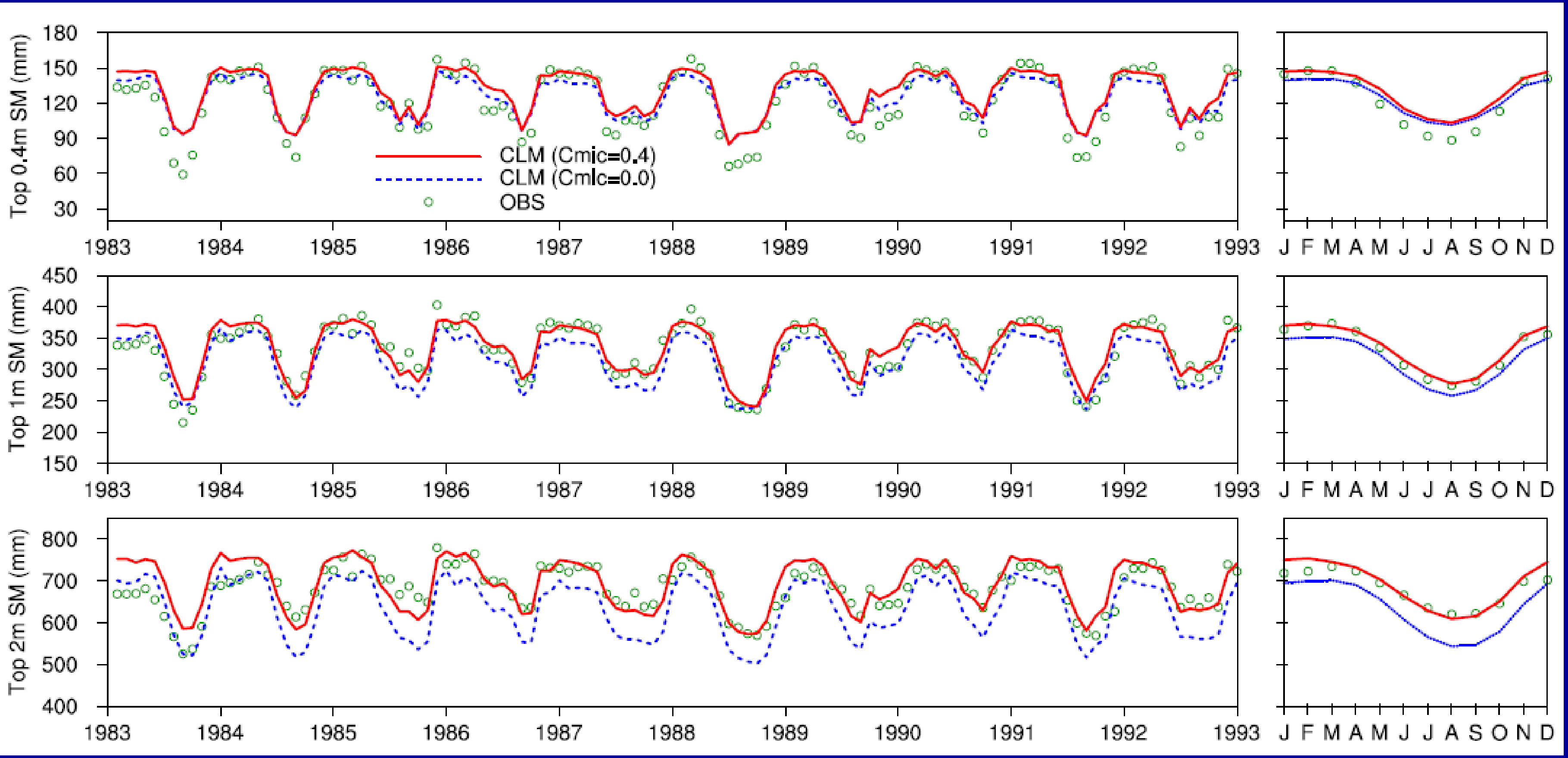
Stomatal resistance: Ball-Berry
Soil moisture stress factor : metric potential
Micropore degree: Cmic = 0.0 (free drainage)

Soil moisture numerical scheme:
CLM vs. Noah



Noah LSM with CLM schemes

CLM soil moisture numerical scheme
Soil moisture stress factor: CLM
Stomatal resistance: Ball-Berry
also changed s1 = 0.5*(SMC(k)+SMC(min(nsoil,k+1)))/smcmax
to s1 = SMC(k)/smcmax
Micropore degree: $C_{mic} = 0.0$ vs. $C_{mic} = 0.4$

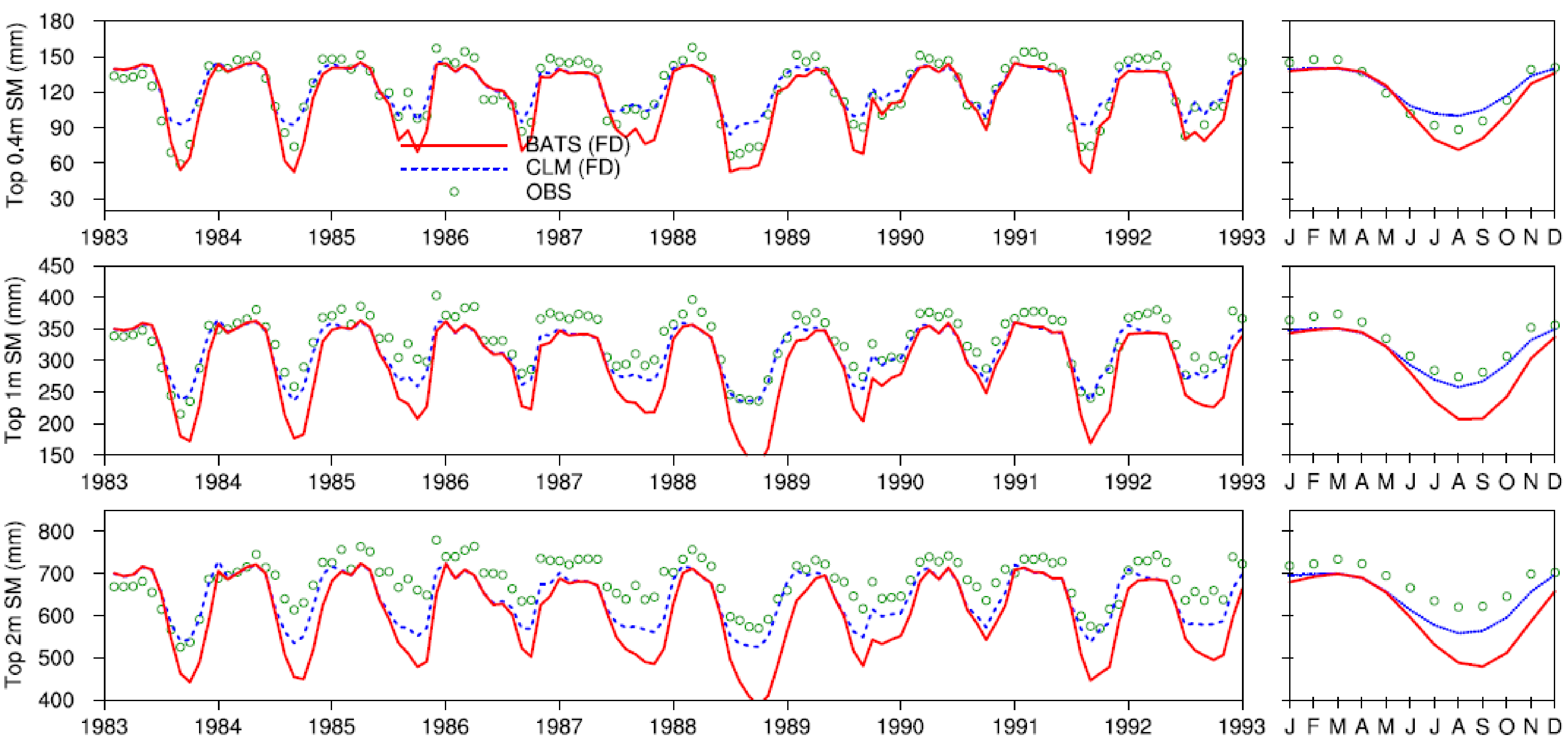


Noah LSM with CLM Schemes

CLM soil moisture numerical scheme
Stomatal resistance: Ball-Berry
Micropore degree: Cmic = 0.0 (Free drainage)

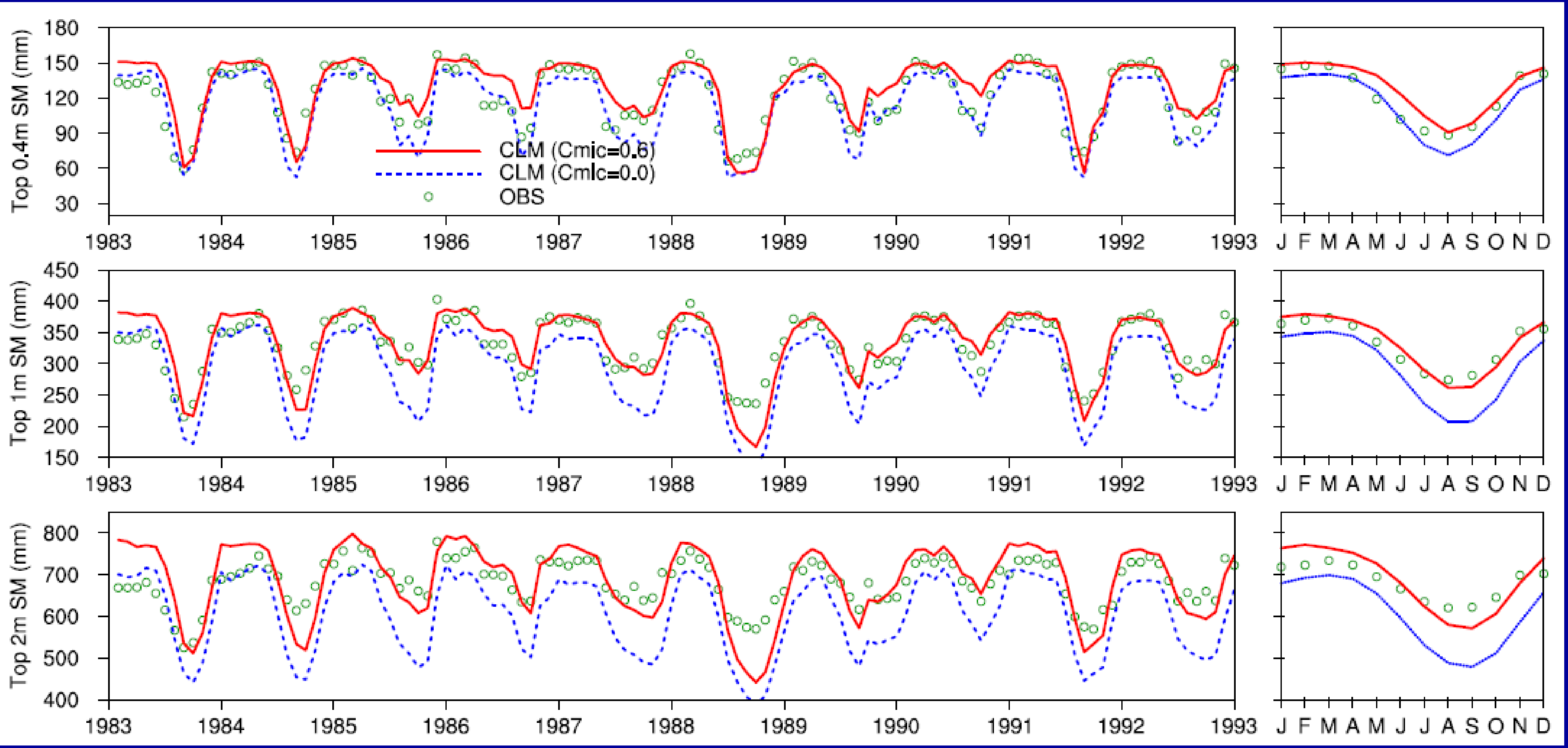
Soil moisture stress factor: btran

CLM vs. BATS



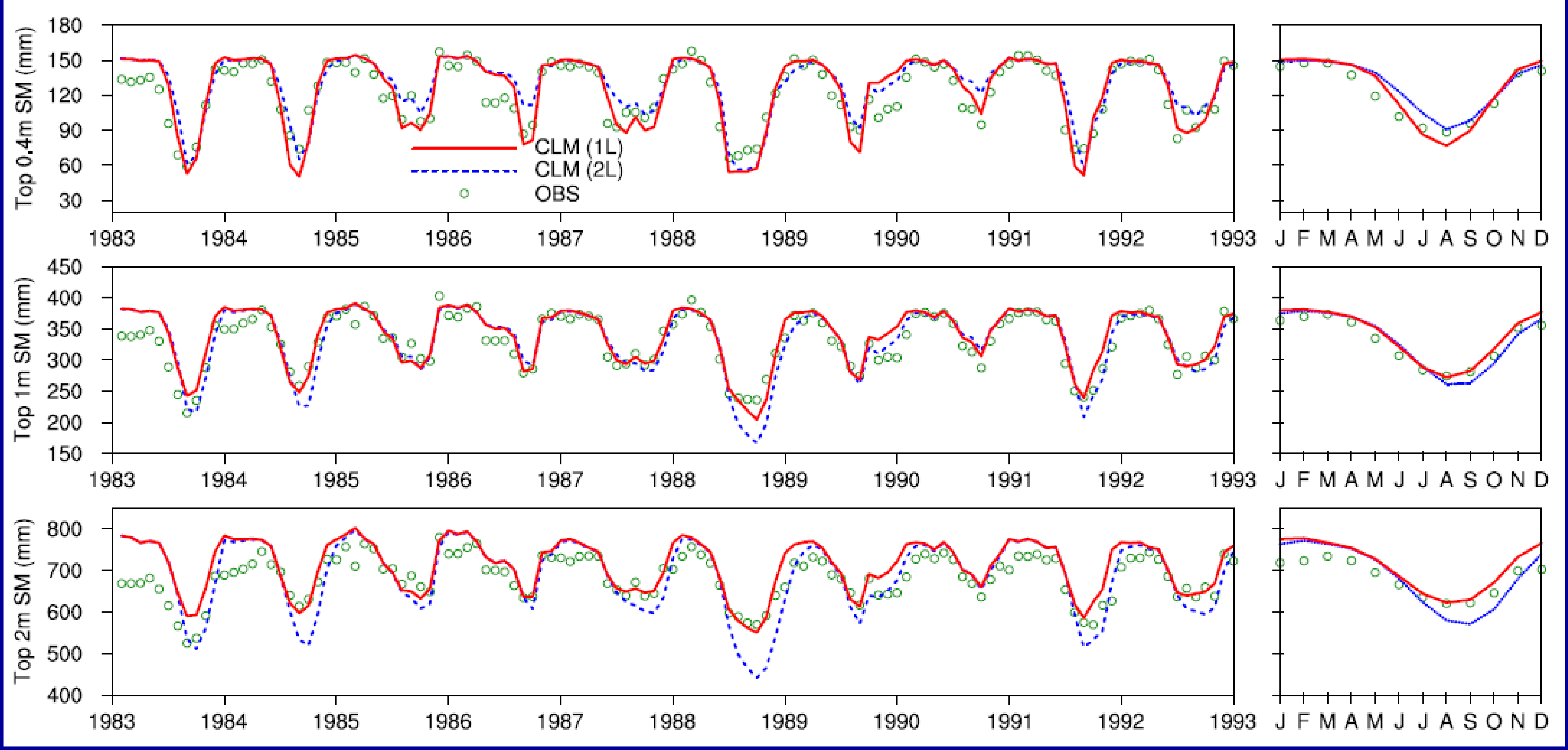
Noah LSM with CLM schemes

CLM soil moisture scheme
Soil moisture stress factor: BATS
Stomatal resistance: Ball-Berry
Micropore degree: C_{mic} = 0.0 vs. C_{mic} = 0.6



Noah LSM with CLM schemes:

CLM soil moisture scheme
Soil moisture stress factor: BATS
Stomatal resistance: Ball-Berry
Micropore degree: Cmic = 0.6
2L averaged SM vs. 1L SM to compute hydraulic conductivity



Summary:

Groundwater is really important for modeling soil moisture, both for mean-state and variability.

We propose to modify SIMGM to account for macropore effects:

1. Enlarge recharge rate from soil to aquifer and
2. Limit the upward flow from aquifer to soil; and
3. Enlarge groundwater discharge rate (to avoid overflow to soil)

C_{mic} is an important calibration parameter and largely depends on surface schemes, e.g., formulations of soil moisture stress factor, although it should depend on deep soil structure.

Larger C_{mic} for larger E at the surface;
Smaller C_{mic} for smaller E at the surface