CLM Development

From Diagnostic to Prognostic
Canopy Airspace
&
From Iterative to Matrix Solution

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References

1. SiB3 code (Ian Baker)

2. Vidale & Stöckli, Theor. Appl. Climatol. Prognostic canopy air space solutions for land surface exchanges, 2005

3. SiB2.5 code (Reto Stöckli)

What are we changing in CLM3?

CLM3 Heat & Vapor Flux Equations at *t*

solving for $T_v^{t+1} \ldots T_s^{t+1} \ldots q_s^{t+1}$

Heat

$$H = -\frac{\rho_{atm} C_p}{r_{ah}} \left(\theta_{atm} - T_s \right)$$

$$H_g = -\frac{\rho_{atm} C_p}{r_{ah'}} \left(T_s - T_g \right)$$

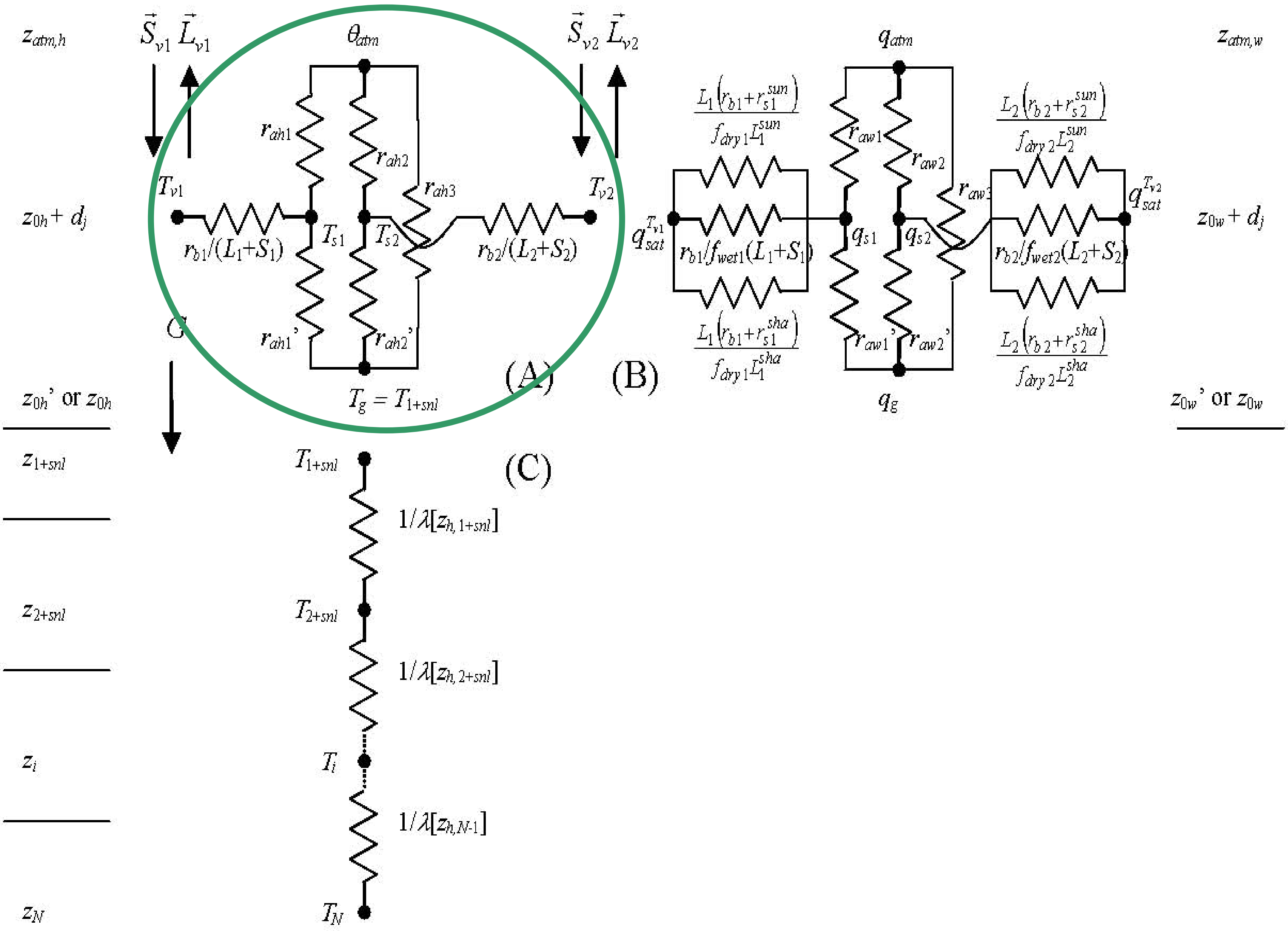
$$H_v = -\rho_{atm} C_p \frac{L+S}{r_b} \left(T_s - T_v \right)$$

$$\left. \begin{array}{l} \rho_{atm} C_p \Delta z \dfrac{\Delta T_s}{\Delta t} = H_g + H_v - H \\ \rho_{atm} C_p \lim\limits_{\Delta z \to 0} (\Delta z) \dfrac{\Delta T_s}{\Delta t} = 0 \end{array} \right\} \Rightarrow H = H_g + H_v$$

← **NO CANOPY STORAGE**

$$T_s = \frac{\dfrac{1}{r_{ah}} \theta_{atm} + \dfrac{1}{r_{ah}'} T_g + \dfrac{L+S}{r_b} T_v}{\dfrac{1}{r_{ah}} + \dfrac{1}{r_{ah}'} + \dfrac{L+S}{r_b}}$$

CLM3 Heat & Vapor Flux Equations at *t*



CLM3 Heat & Vapor Flux Equations at t

solving for $T_v^{t+1} \ldots T_s^{t+1} \ldots q_s^{t+1}$

Heat

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$$\left.\begin{aligned} \rho_{atm} C_p \Delta z \frac{\Delta T_s}{\Delta t} &= H_g + H_v - H \\ \rho_{atm} C_p \lim_{\Delta z \to 0} (\Delta z) \frac{\Delta T_s}{\Delta t} &= 0 \end{aligned}\right\} \Rightarrow H = H_g + H_v$$

Vapor

$$\lambda_{vap} E = -\frac{\rho_{atm} \lambda_{vap}}{r_{aw}} (q_{atm} - q_s)$$

$$\lambda_{vap/sub} E_g = -\frac{\rho_{atm} \lambda_{vap/sub}}{r_{aw'}} (q_s - q_g)$$

$$\lambda_{vap} E_v = -\rho_{atm} \lambda_{vap} \left\{ f_{wet} \frac{L+S}{r_b} + \frac{f_{dry}}{L} \left(\frac{L^{sun}}{r_b + r_s^{sun}} + \frac{L^{sha}}{r_b + r_s^{sha}} \right) \right\} (q_s - q_{sat}^{T_v})$$

$$E = E_g + E_v$$

Canopy Energy Conservation

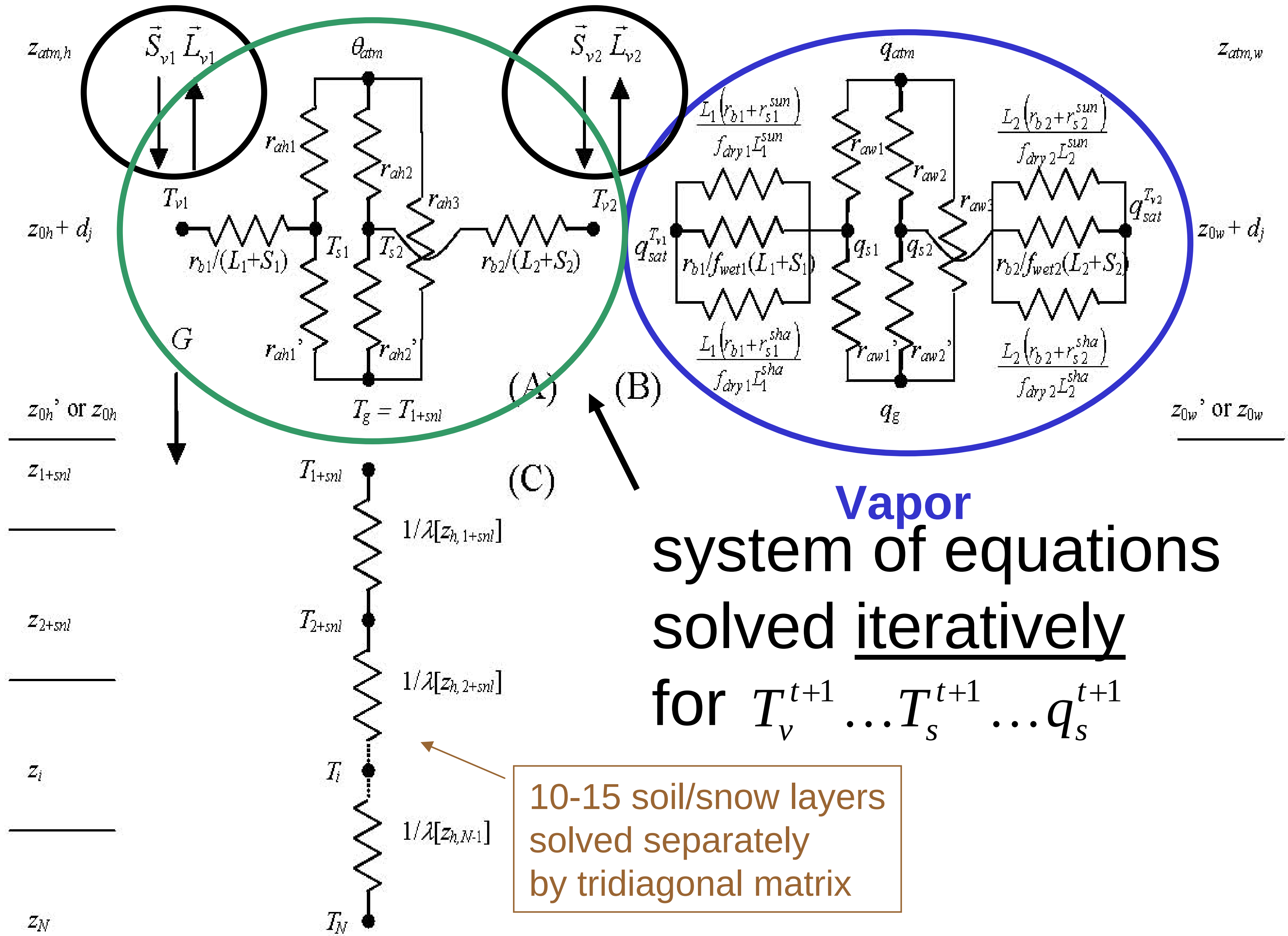
$$\vec{S}_v - \vec{L}_v - H_v - \lambda_{vap} E_v = 0$$

NO CANOPY STORAGE

$$T_s = \frac{\frac{1}{r_{ah}} \theta_{atm} + \frac{1}{r_{ah}'} T_g + \frac{L+S}{r_b} T_v}{\frac{1}{r_{ah}} + \frac{1}{r_{ah}'} + \frac{L+S}{r_b}}$$

$$q_s = \frac{\frac{1}{r_{aw}} q_{atm} + \frac{1}{r_{aw}'} q_g + \frac{L+S}{r_b} \left[f_{wet} + \frac{f_{dry} r_b}{L} \left(\frac{L^{sun}}{r_b + r_s^{sun}} + \frac{L^{sha}}{r_b + r_s^{sha}} \right) \right] q_{sat}^{T_v}}{\frac{1}{r_{aw}} + \frac{1}{r_{aw}'} + \frac{L+S}{r_b} \left[f_{wet} + \frac{f_{dry} r_b}{L} \left(\frac{L^{sun}}{r_b + r_s^{sun}} + \frac{L^{sha}}{r_b + r_s^{sha}} \right) \right]}$$

CLM3 Heat & Vapor Flux Equations at t



system of equations solved <u>iteratively</u> for $T_v^{t+1} \ldots T_s^{t+1} \ldots q_s^{t+1}$

10-15 soil/snow layers solved separately by tridiagonal matrix

The Prognostic Equations

same but with storage terms

$$\rho_{atm} C_p \Delta z \frac{\Delta T_s}{\Delta t} = H_g + H_v - H$$

Heat: T_s

$$\rho_{atm} \lambda_{vap} \Delta z \frac{\Delta q_s}{\Delta t} = \lambda_{vap/sub} E_g + \lambda_{vap} E_v - \lambda_{vap} E$$

Vapor: q_s

$$c_v \frac{\Delta T_v}{\Delta t} = \vec{S}_v - \vec{L}_v - H_v - \lambda_{vap} E_v$$

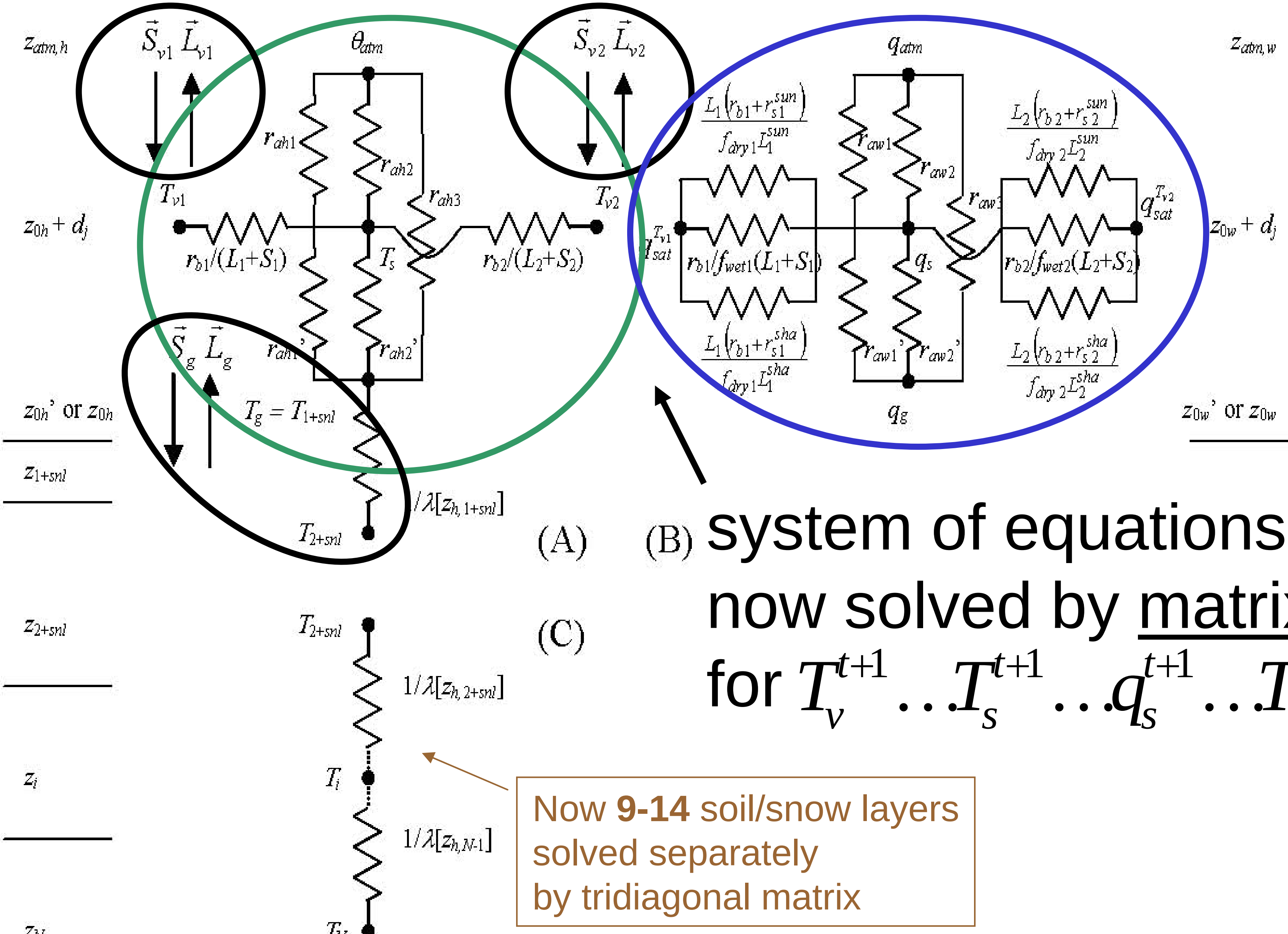
Canopy Energy Conservation: T_v

moved up:

$$c_{soil,1+snl} \frac{\Delta T_g}{\Delta t} = \vec{S}_g - \vec{L}_g - H_g - \lambda_{vap/sub} E_g - F_{1+snl}$$

Ground Energy Conservation: T_g

The Prognostic Equations



system of equations now solved by <u>matrix</u> for $T_v^{t+1} \ldots T_s^{t+1} \ldots q_s^{t+1} \ldots T_g^{t+1}$

Now **9-14** soil/snow layers solved separately by tridiagonal matrix

Summary

1. Account for vapor & heat <u>storage</u> in canopy
2. Solve for *T* and *q* variables in <u>one step</u>

- improve stability of calculations
- easily introduce isotopes (H_2O, C)
- simplify code

The New Matrix

$$A \cdot x = B$$

(Eq. 5)

$$\begin{pmatrix} C_{T_s}^1 & C_{q_s}^1 & C_{T_v}^1 & C_{T_g}^1 \\ C_{T_s}^2 & C_{q_s}^2 & C_{T_v}^2 & C_{T_g}^2 \\ C_{T_s}^3 & C_{q_s}^3 & C_{T_v}^3 & C_{T_g}^3 \\ C_{T_s}^4 & C_{q_s}^4 & C_{T_v}^4 & C_{T_g}^4 \end{pmatrix} \cdot \begin{bmatrix} \Delta T_s \\ \Delta q_s \\ \Delta T_v \\ \Delta T_g \end{bmatrix} = \begin{bmatrix} F_{T_s} \\ F_{q_s} \\ F_{T_v} \\ F_{T_g} \end{bmatrix}$$

← Heat Flux Equation
← Vapor Flux Equation
← Canopy Energy Conservation
← Ground Energy Conservation

We rewrite Eq. 5 for the general case of multiple pfts, j:

$$\begin{pmatrix} C_{T_s}^1 & 0 & C_{(T_v)_j}^1 & C_{T_g}^1 \\ 0 & C_{q_s}^2 & C_{(T_v)_j}^2 & C_{T_g}^2 \\ C_{T_s}^{2+j} & C_{q_s}^{2+j} & C_{(T_v)_j}^{2+j} & C_{T_g}^{2+j} \\ C_{T_s}^{3+npft} & C_{q_s}^{3+npft} & C_{(T_v)_j}^{3+npft} & C_{T_g}^{3+npft} \end{pmatrix} \times \begin{bmatrix} \Delta T_s \\ \Delta q_s \\ \Delta (T_v)_j \\ \Delta T_g \end{bmatrix} = \begin{bmatrix} F_{T_s} \\ F_{q_s} \\ F_{(T_v)_j} \\ F_{T_g} \end{bmatrix} \quad \text{(Eq. 7)}$$

PCAS Implementation in CLM

- **Implementing PCAS scheme into CLM from Sam's "toy model"**
- **On a CLM branch in the NCAR subversion repository**
- **New code in *src/biogeophys/CanopyAirSpaceMod.F90***
- **Two new variables will be computed and output to history files:**
  - **FIRA_V - net longwave radiation from vegetation**
  - **FIRA_G - net longwave radiation from the ground**
- **Projected timeline for implementation:**
  - **Prototype code running in CLM by the Breckenridge meeting**
  - **Detailed testing in offline and coupled configurations in the fall**
  - **If all goes well, incorporate scheme into CLM4 by the end of 2007**

Time differencing scheme

However, before entering the terms from Eqs. 1 to 4 into Eq. 5, we rewrite the equations so as to employ a time-differencing scheme that improves the accuracy of the solution.

4. Numerical Implementation

We transform Eqs. 1 to 4 algebraically assuming an implicit scheme with explicit coefficients. Terms that depend on the variables that we are solving for are indexed $n + 1$ (implicit scheme), while other terms, e.g. solar radiation and various coefficients, are indexed n (explicit coefficients) (Kalnay and Kanamitsu 1988):