ARTICLE

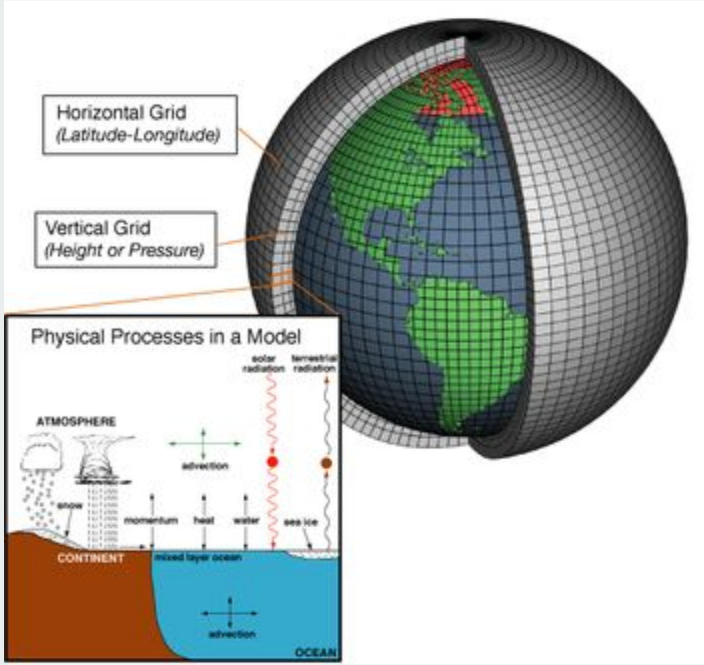
Modeling the Exchanges of Energy, Water, and Carbon Between Continents and the Atmosphere

P. J. Sellers,* R. E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, G. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, N. Sato, C. B. Field, A. Henderson-Sellers

Important Terms

AGCM → Atmospheric General Circulation Model

LSP → Land Surface Parameterization



"In AGCMs, the motion of the atmosphere is defined by fluid dynamics equations that incorporate the mechanical forces of gravity, the Earth's rotation, pressure and temperature gradients, and friction"

First-Generation Models

Three Important Processes

1. Exchanges of radiation
2. Fluxes of sensible and latent heat
3. Frictional deceleration of the lower atmosphere resulting from drag forces as the wind passes over the land

First-Generation Models - Net Radiation

$$R_n = S(1 - \alpha) + L_w - \varepsilon\sigma T_s^4 \qquad (1)$$

$$R_n = G + H + \lambda E \qquad (2)$$

First-Generation Models - Fluxes

$$H = \frac{T_s - T_r}{r_a} \rho c_p \qquad (3)$$

$$\lambda E = \beta \left[\frac{e^*(T_s) - e_r}{r_s} \right] \frac{\rho c_p}{\gamma} \qquad (4)$$

First Generation Models - Findings

- Specification of surface parameters could have important impacts on atmospheric fields

- Experiments were **unrealistic** because fluxes were treated as **independent processes**

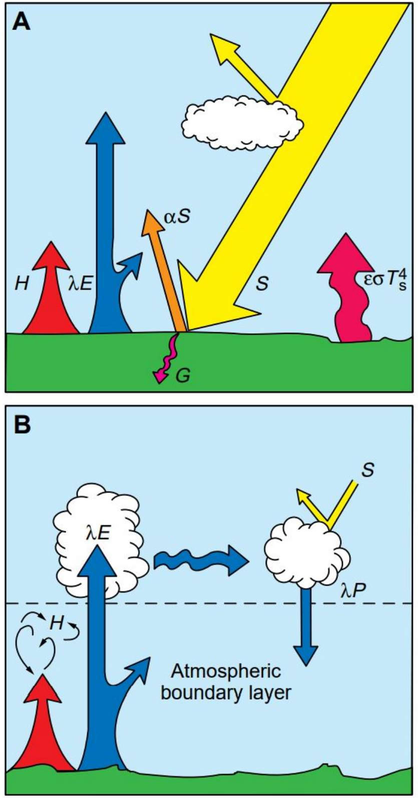
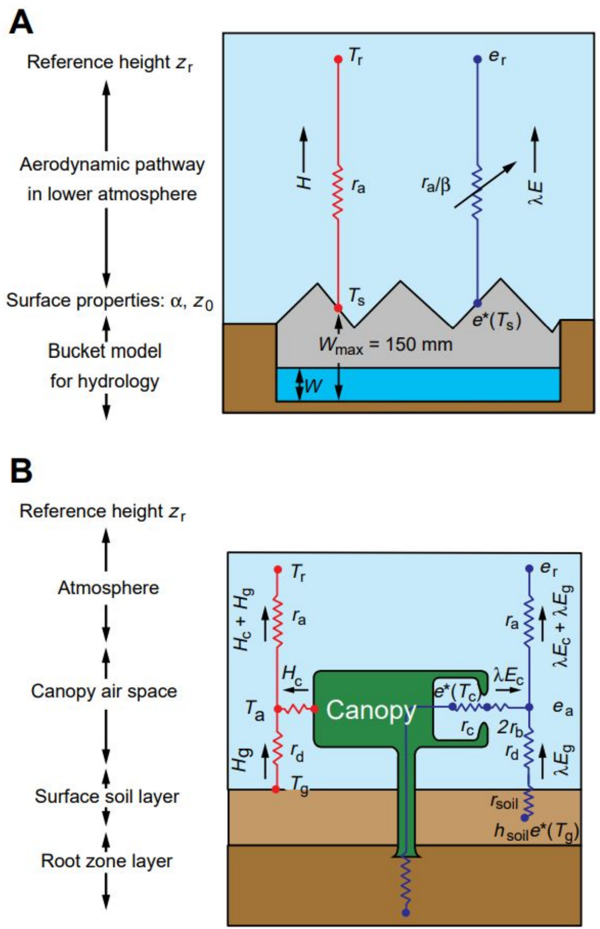


Fig. 1. Interactions between the land surface and the atmosphere that have direct impacts on the physical climate system. (**A**) Surface radiation budget. (**B**) Effect of heat fluxes on the atmosphere.

Second Generation Models

- Explicitly recognizing the effects of **vegetation** in calculations of the surface energy balance

- Modeling the vegetation-soil system itself



Second Generation Models - Biophysical LSPs

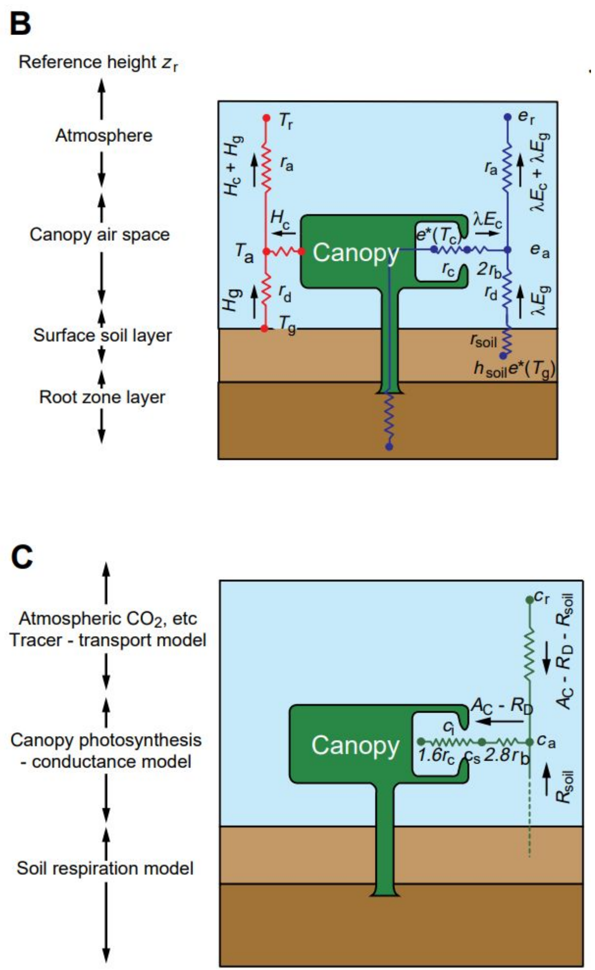
- Radiation Absorption
- Momentum transfer
- Biophysical control of evapotranspiration
- Precipitation interception and interception loss
- Soil moisture availability
- Insulation

Second-Generation Models - Results

The incorporation of biophysics into the second-generation LSPs made them **internally consistent**, **realistic**, and **capable of calculating surface-atmosphere fluxes more accurately** than their first-generation counterparts.

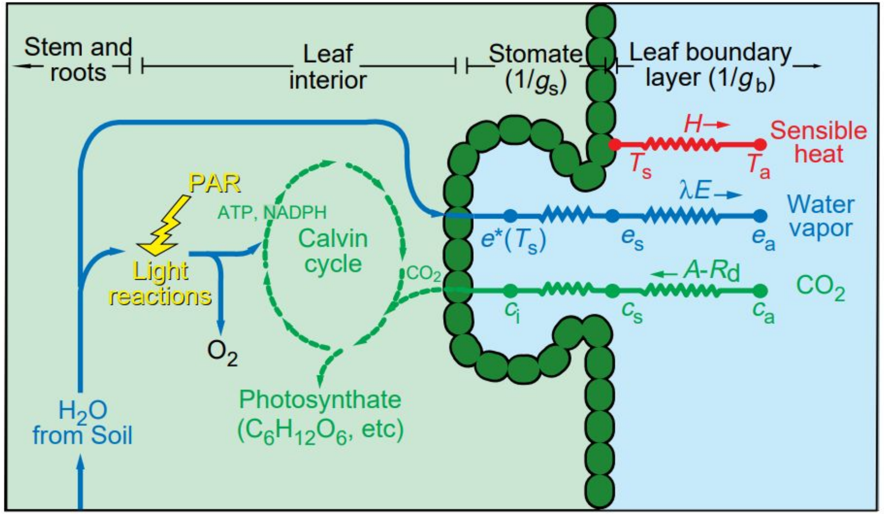
Third-Generation Models

- Focused on global change
- Modern theories relating photosynthesis and plant water relations



Third-Generation Models - Limiting Factors

1. Enzyme kinetics
2. Electron Transport
3. Chlorophyll Efficiency



Third-Generation Models - Stomatal Conductance

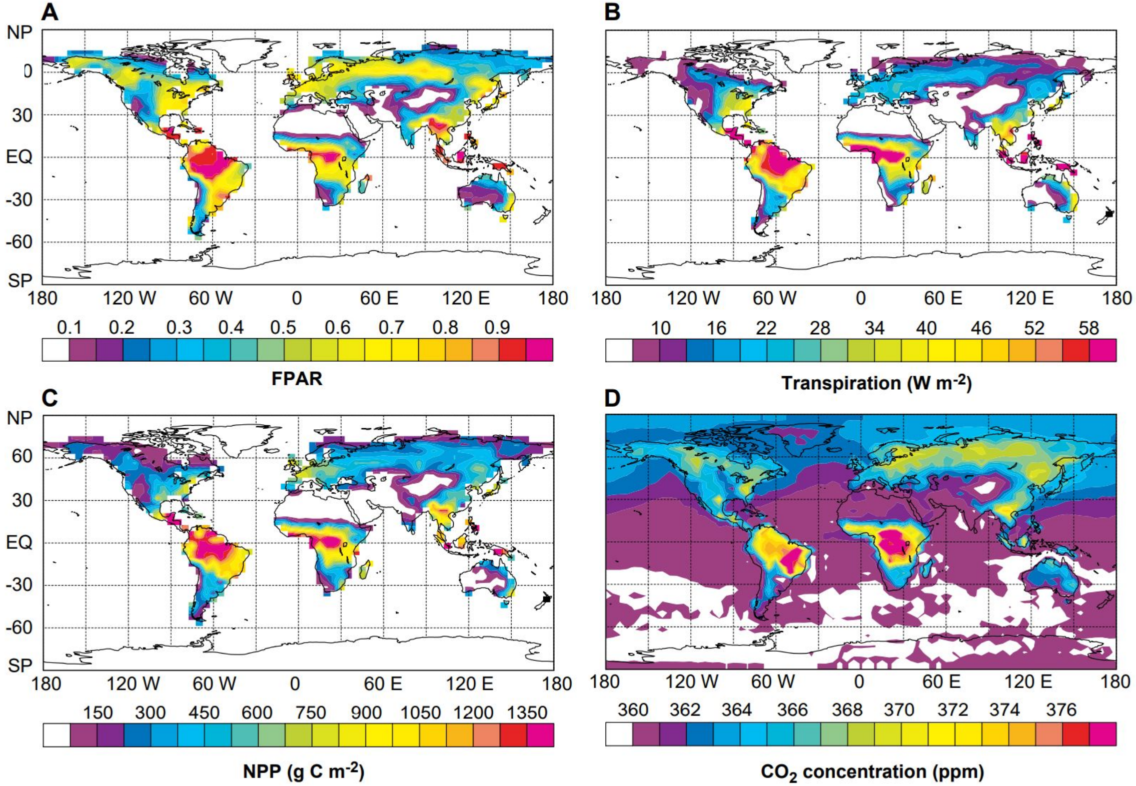
$$g_s = m\frac{A_n}{c_s}h_s p + b \qquad (7)$$

$$A_c, g_c = [V_{max0}, PAR_0][B_1 . . . B_6][\Pi] \qquad (8)$$

Third-Generation Models - SVI's and Remote Sensing

$$\Pi = \mathrm{FPAR}/\bar{k} \propto \mathrm{SR} = a_{\mathrm{N}}/a_{\mathrm{V}} \qquad (9)$$

- SVI values should be near linearly related to FPAR over a wide range of conditions.
- LAI, and hence albedo and roughness length, can be used directly by third-generation LSPs.



A
NP
0
30
EQ
-30
-60
SP
180
120 W
60 W
0
60 E
120 E
180
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
FPAR
B
10 16 22 28 34 40 46 52 58
Transpiration (W m-2)
C
NP
60
30
EQ
-30
-60
SP
150 300 450 600 750 900 1050 1200 1350
NPP (g C m-2)
D
360 362 364 366 368 370 372 374 376
CO2 concentration (ppm)

Development of Remote Sensing Techniques

- The most **feasible**, **consistent**, and **accurate** means of providing global fields of land surface parameters
- Simple “aggregation” rules

“Large-scale physiological and physical climate system effects will both be important in determining the rate of increase in atmospheric CO2 and the physical and biological responses of the Earth system to it over the next few decades (49). The need for realistic and accurate models becomes more urgent”

Work Cited

P. J. Sellers, R. E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, G. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, N. Sato, C. B. Field, A. Henderson-Sellers, Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science* **275**, 502–509 (1997).