Representing Land Cover Heterogeneity in CLM4

ZL Yang

References:
Yang (2004)
Bonan (2008) Ecological Climatology
Oleson et al. (2010)

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IGBP DISCover Data Set Land Cover Classification System

CLASS	CLASS NAME	DESCRIPTION
1	Evergreen Needleleaf Forests	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.
2	Evergreen Broadleaf Forests	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.
3	Deciduous Needleleaf Forests	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
4	Deciduous Broadleaf Forests	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
5	Mixed Forests	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of tree communities with interspersed mixtures or mosaics of the other four forest cover types. None of the forest types exceeds 60% of landscape.
6	Closed Shrublands	Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is >60%. The shrub foliage can be either evergreen or deciduous.
7	Open Shrublands	Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is between 10-60%. The shrub foliage can be either evergreen or deciduous.
8	Woody Savannas	Lands with herbaceous and other understorey systems, and with forest canopy cover between 30-60%.The forest cover height exceeds 2 meters.
9	Savannas	Lands with herbaceous and other understorey systems, and with forest canopy cover between 10-30%.The forest cover height exceeds 2 meters.
10	Grasslands	Lands with herbaceous types of cover. Tree and shrub cover is less than 10%.
11	Permanent Wetlands	Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas. The vegetation can be present in either salt, brackish, or fresh water.
12	Cropland	Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems. Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.
13	Urban and Built-up	Land covered by buildings and other man-made structures. Note that this class will not be mapped from the AVHRR imagery but will be developed from the populated places layer that is part of the Digital Chart of the World.
14	Cropland/Natural Vegetation Mosaics	Lands with a mosaic of croplands, forest, shrublands, and grasslands in which no one component comprises more than 60% of the landscape.
15	Snow and Ice	Lands under snow and/or ice cover throughout the year.
16	Barren	Lands exposed soil, sand, rocks, or snow and never has more than 10% vegetated cover during any time of the year.
17	Water Bodies	Oceans, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water bodies

Many land models classify vegetation by biomes, similar or identical to the IGBP system.

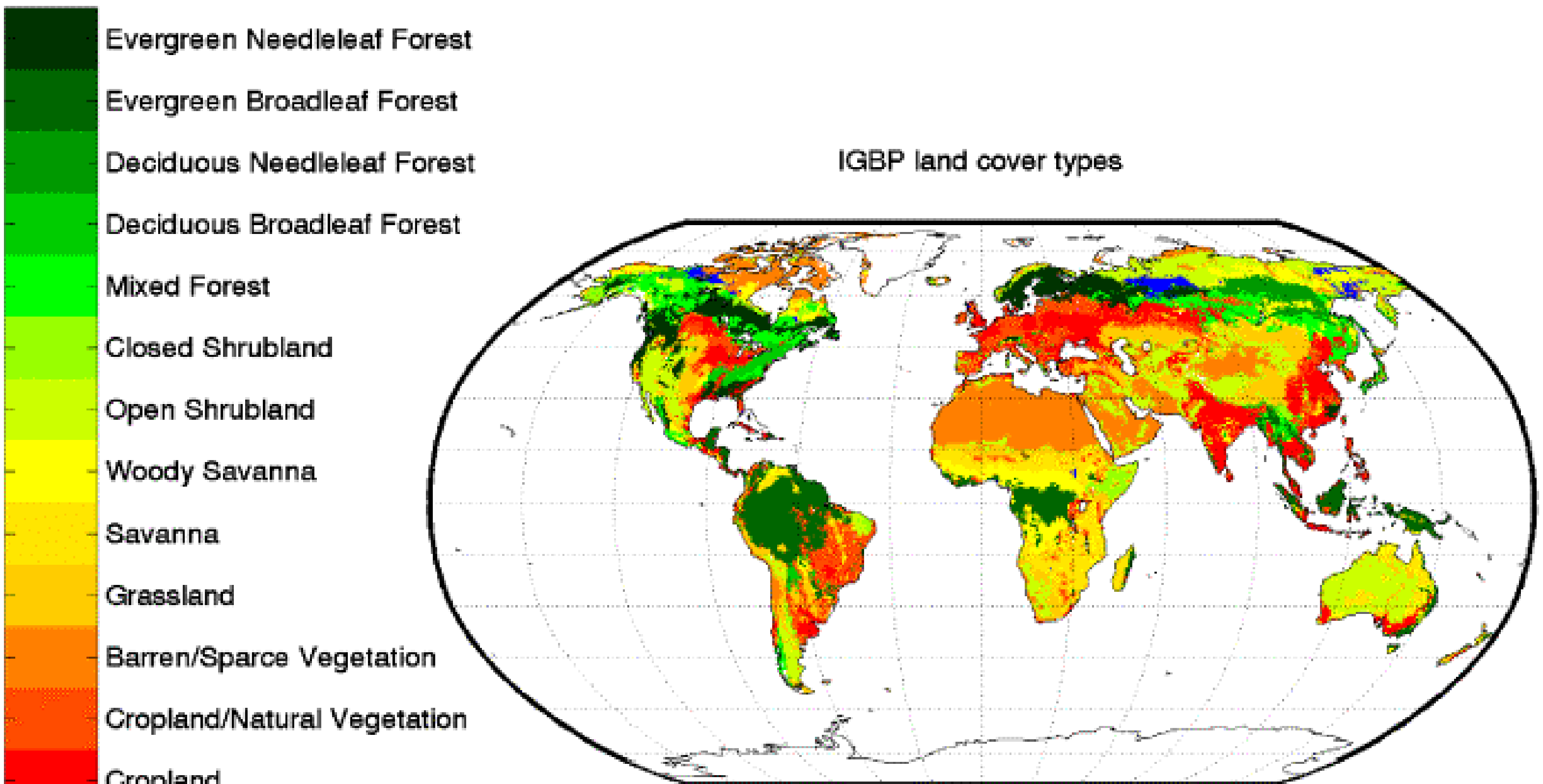
Parameters: albedo (VIS, NIR), roughness length, vegetation coverage (FVmax), LAI (max, min), rooting depth, and minimum stomatal resistance; see Table 25.2 in Bonan (2008) or Dickinson et al. (2003).

Advantages: reasonable top-down modeling approach to computing surface energy, water, and momentum fluxes for atmospheric models.

Disadvantages: difficult to obtain leaf physiological and whole-plant carbon allocation parameters for mixed life-form biomes (e.g., savanna).

http://www.fao.org/forestry/4031-0b6287f13b0c2adb3352c5ded18e491fd.pdf

Biome Representation Of Land Cover



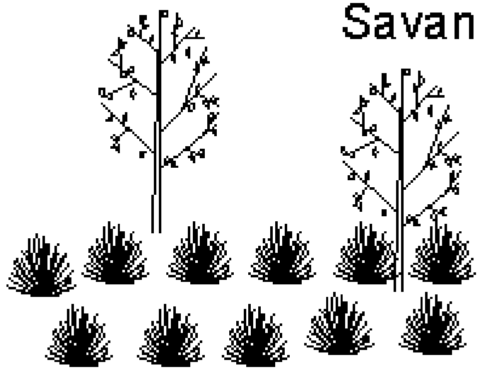
Biomes determine:

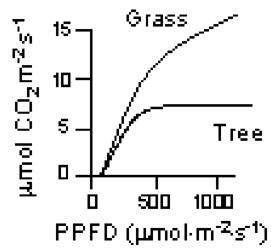
- Plant physiology (e.g., Vmax)
- Leaf and stem optical properties
- Roughness length
- Leaf and stem area index

http://www.cgd.ucar.edu/tss/clm/pfts/igbp.gif

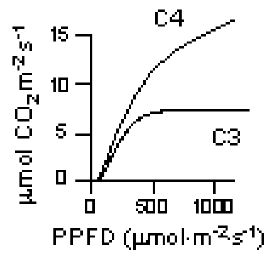
Mixed Life-Form Biomes

Savanna

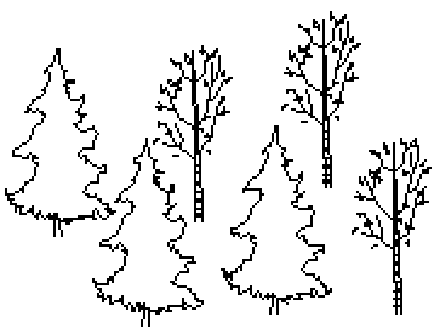


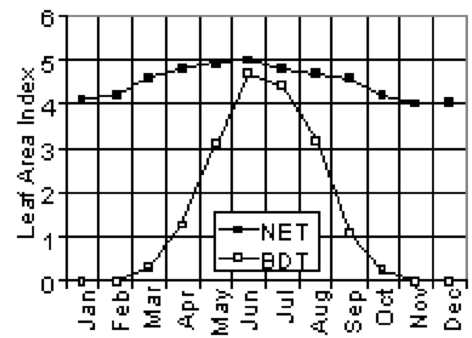


Grassland



Mixed Forest





http://www.cgd.ucar.edu/tss/clm/pfts/biome-vs-pft.gif

Plant Functional Types

Climate Rules

Remote Sensing Data Products	→	Plant Functional Types
Needleleaf evergreen tree		temperate boreal
Needleleaf deciduous tree		boreal
Broadleaf evergreen tree		tropical temperate
Broadleaf deciduous tree		tropical temperate boreal
Shrub		broadleaf evergreen temperate broadleaf deciduous temperate broadleaf deciduous boreal
Grass		C3 C3 arctic C4
Crop		Crop 1 (e.g., corn) Crop 2 (e.g., wheat)

Trees

1-km U. Maryland tree cover

- needleleaf, broadleaf
- evergreen, deciduous

Others

1-km IGBP DISCover

- shrub, grass, crop

Monthly Leaf Area

- 1-km AVHRR red and near infrared reflectance
- April 1992 to March 1993
- 'Pure PFT' NDVI for 200 km × 200 km grid
- Average NDVI for each 1-km pixel with PFT > 60%

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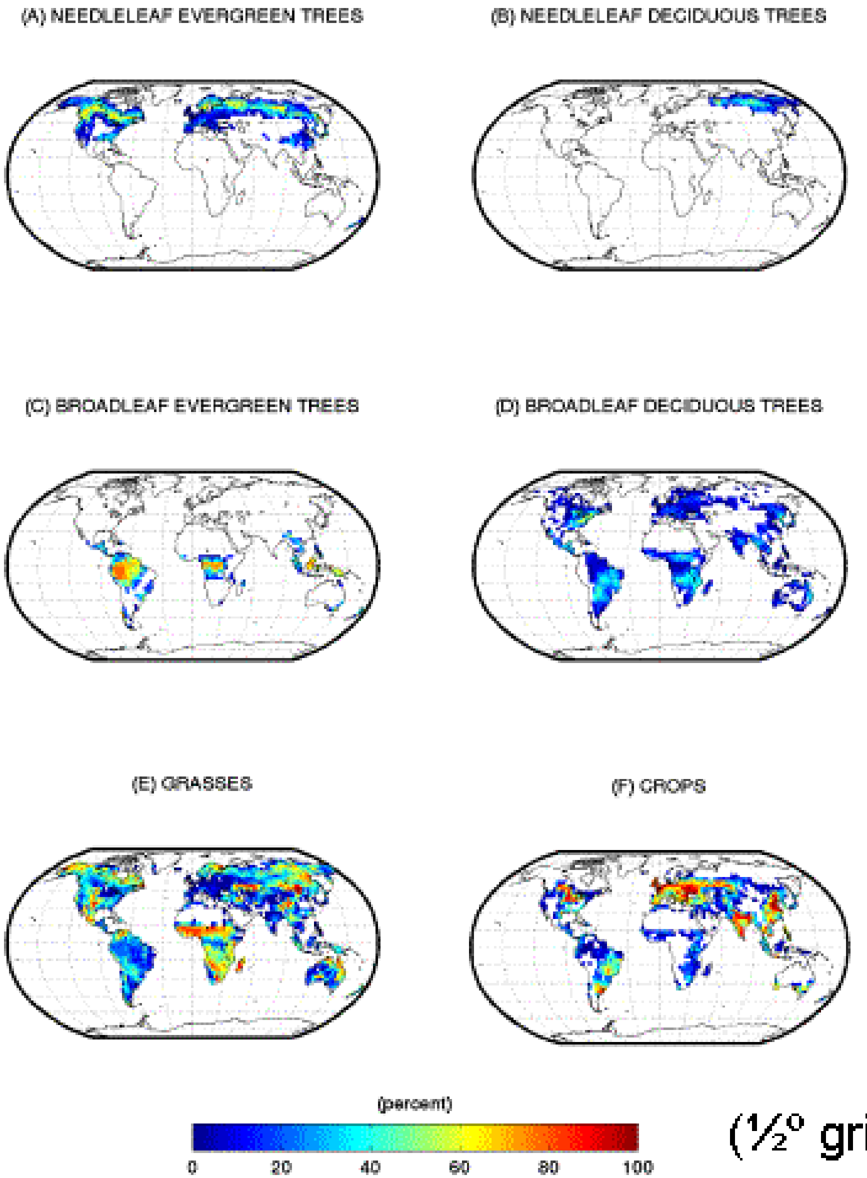
Bonan et al. (2002)

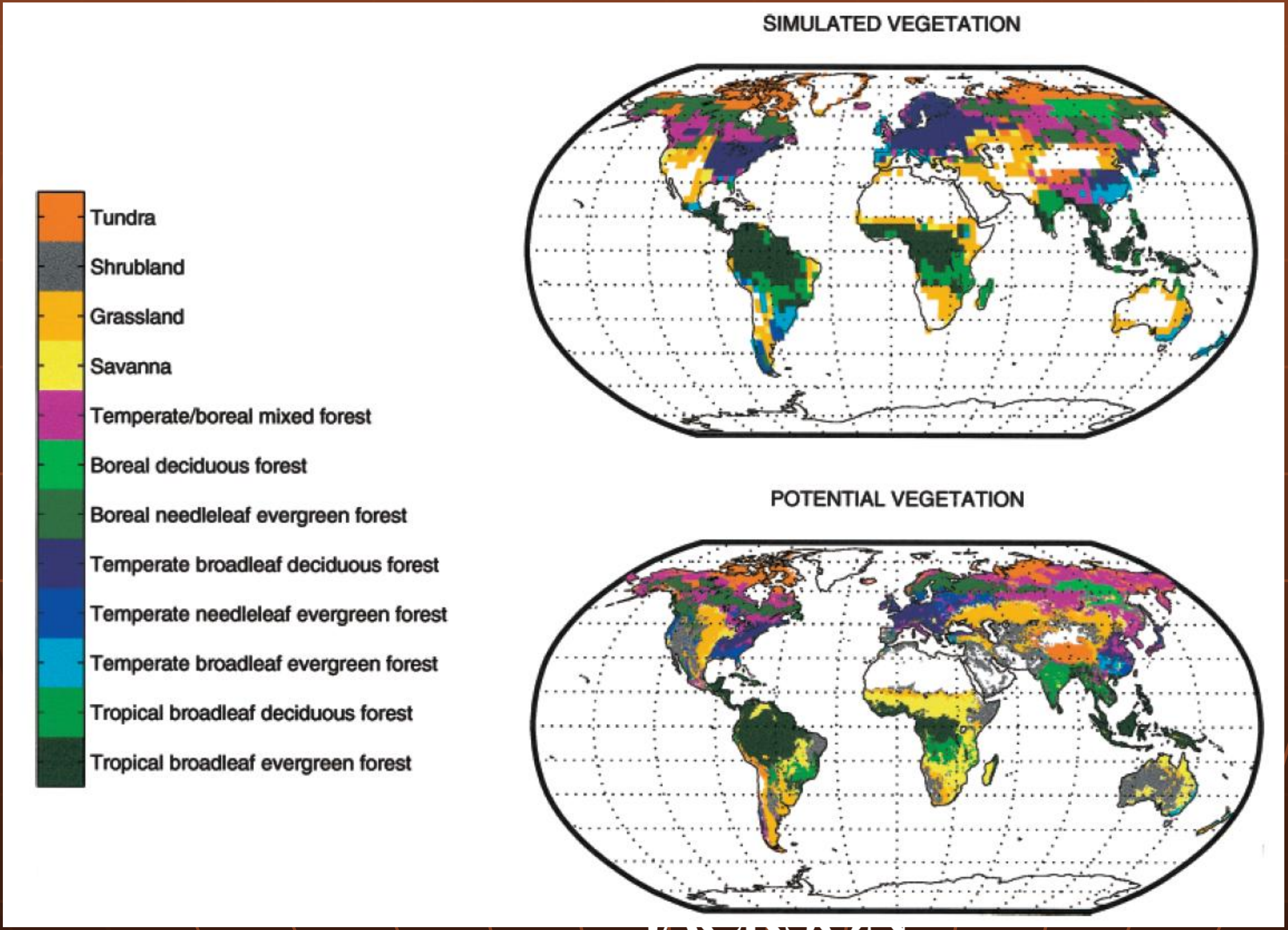
Plant Functional Type Geography



(½° grid)

Bonan et al. (2002)

Global Biogeography



Forcing: 20-yr atmospheric data (1979 –1998) (Bonan et al., 2002)

Model: NCAR LSM linked with LPJ DGVM

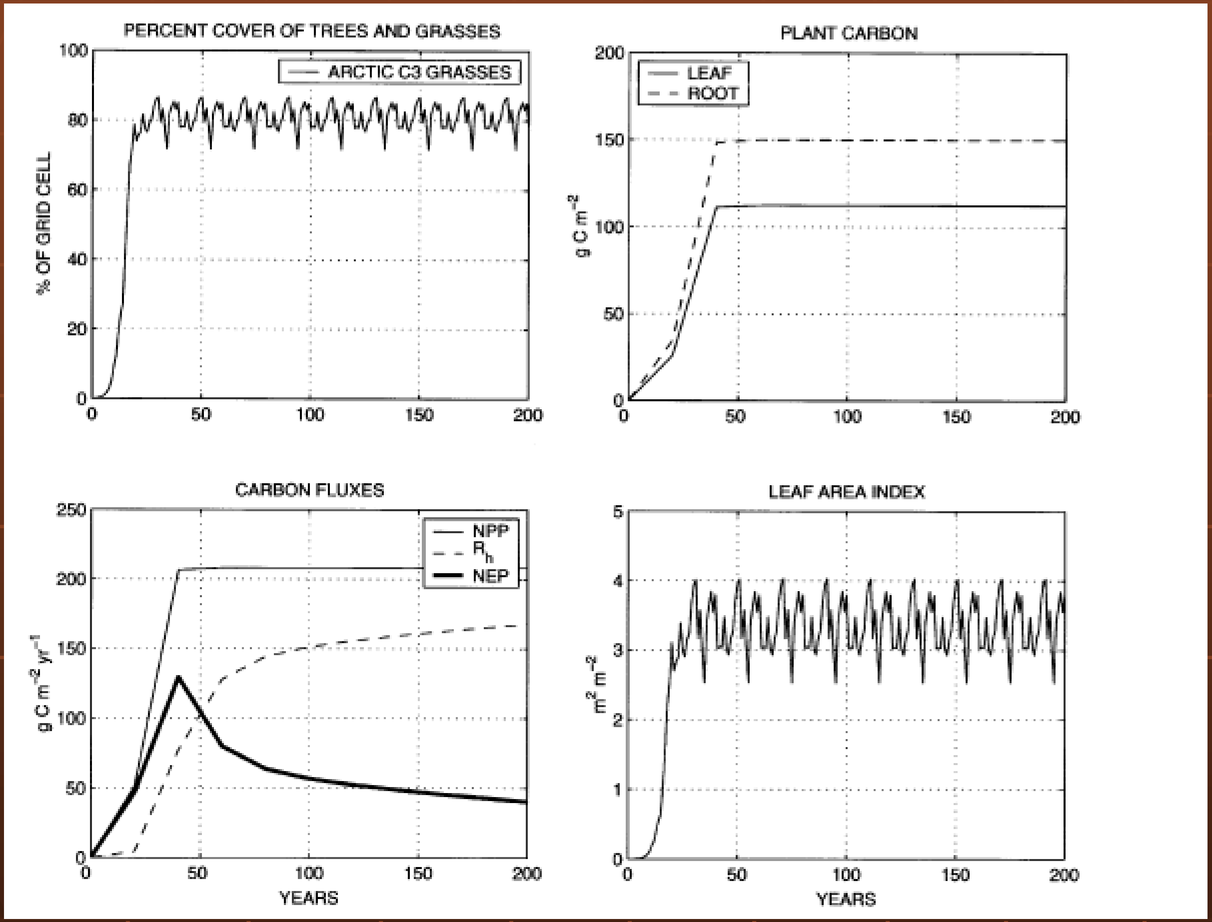
Resolution: 3°×3°

Integration: 200 yrs from bare ground by repeating the 20-yr data 10 times

Comparison: aggregate pfts into biomes and then compare with potential natural vegetation dataset of Ramankutty and Foley (1999)

Bonan et al. (2003); Figure 24.21 in Bonan (2008)

Vegetation Dynamics



A gridcell in the Canadian Arctic (65.5°N, 105.5°W)

LSM-DGVM simulations. Carbon fluxes and biomass are 20-yr average. LAI is the maximum attained each yr.

Starting from an initial bare ground, the model captures the vegetation recovery.

Within less than 25 yrs, plant cover reaches equilibrium at about 80%.

NPP and plant mass recover more slowly, taking about 40 yrs.

Bonan et al. (2003); Fig. 24.22 Bonan (2008)

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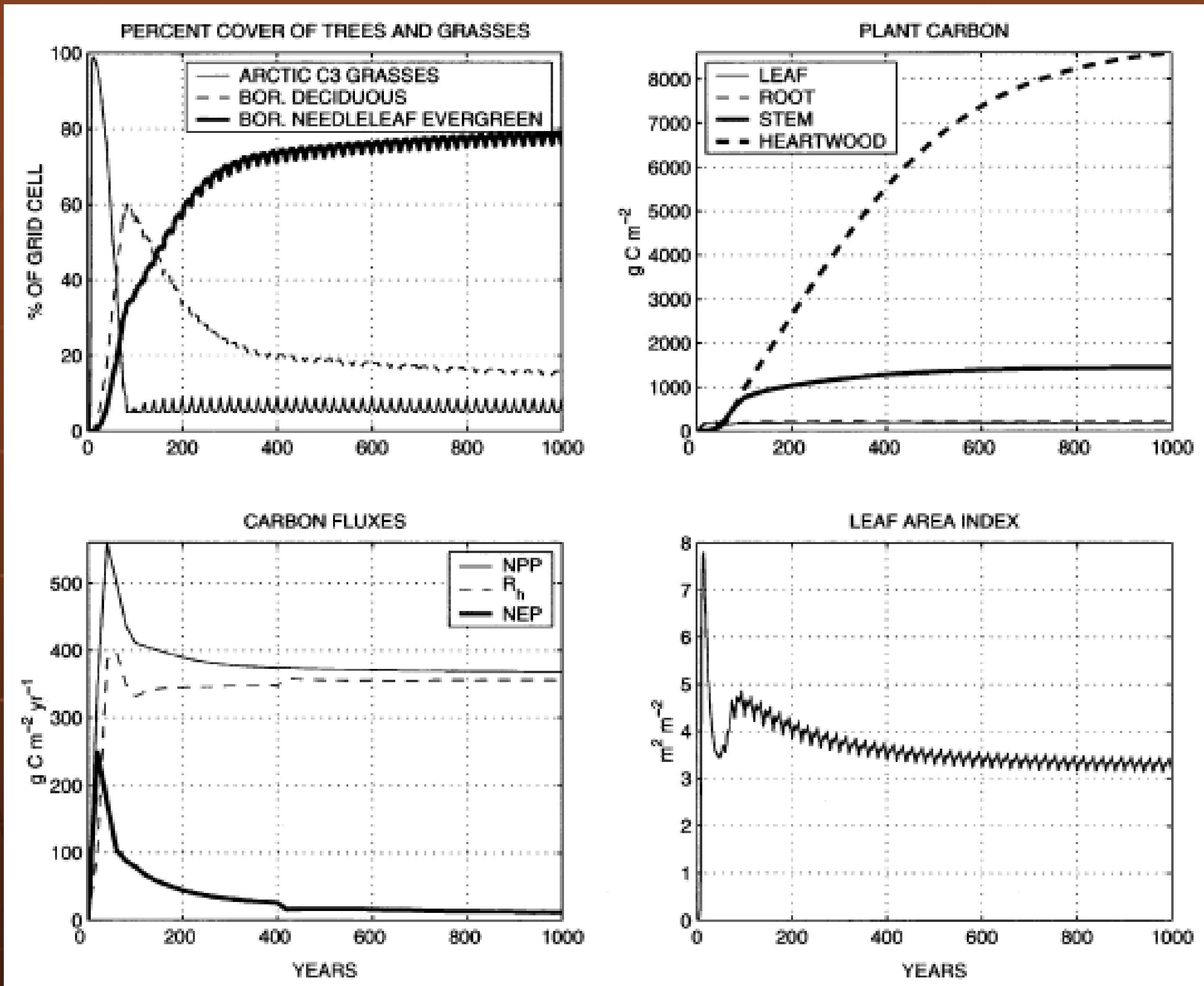
Vegetation Dynamics



A gridcell in the Canadian boreal forest (60.5°N, 105.5°W)

LSM-DGVM simulations

Spinup times:
NPP → 250-300 yrs
Foliage & root mass→ 100 yrs
Stem sapwood & LAI → 500 yrs
Forest composition → 250 yrs (66% evergreen, 28% deciduous, 5% grass), equilibrium at 800 yrs
Heartwood mass → > 1000 yrs

In nature, recurring fires preclude stands much older than 250 yrs.

Grasses: initial dominance, then rapid decline.

Deciduous trees: rapid increase, peaking by 100 yrs, then declining

Evergreen trees dominate over deciduous trees after 145 yrs, increasing to 76% while deciduous down to 15%; compare Fig. 22.11

Bonan et al. (2003); Fig. 24.22 Bonan (2008)

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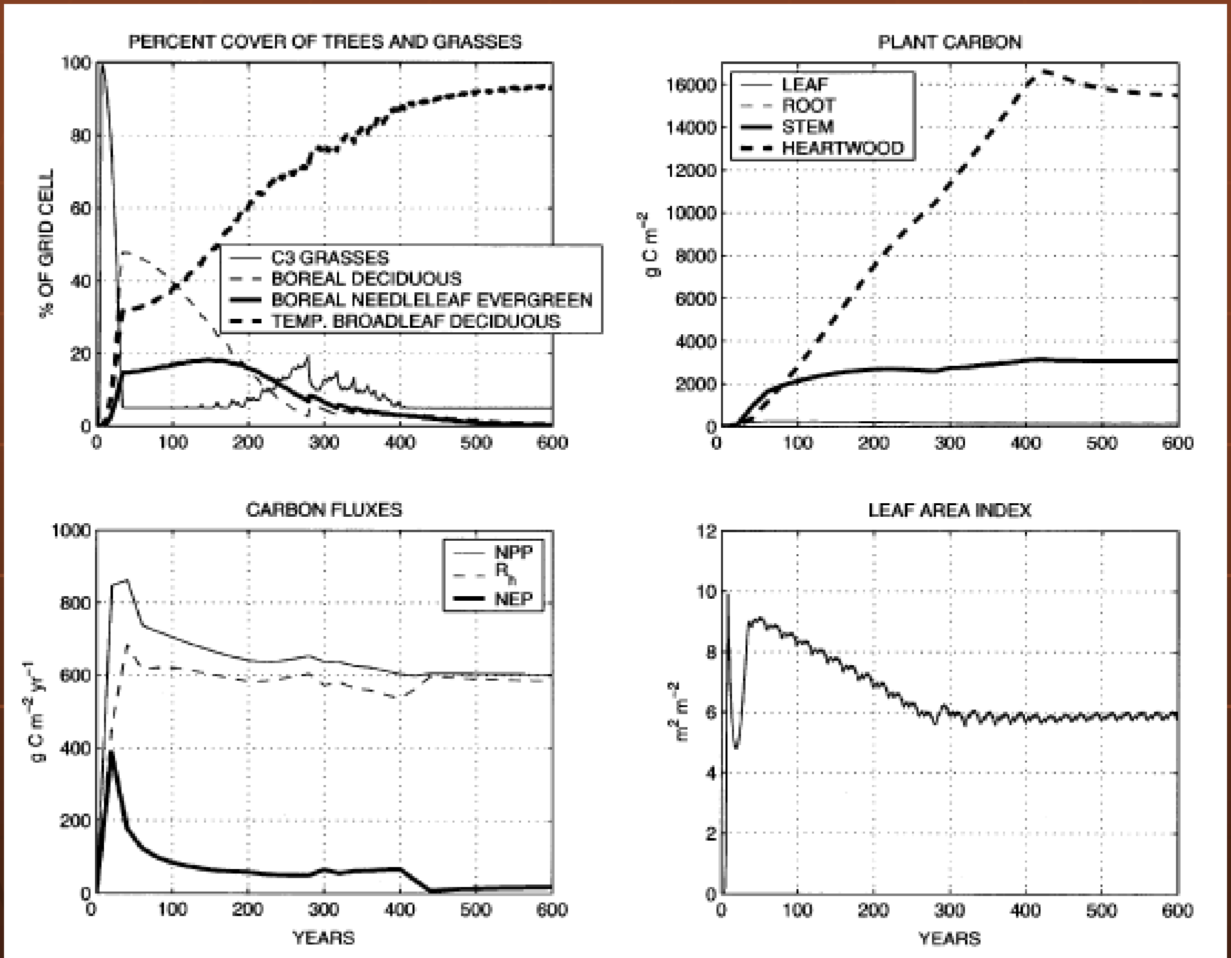
Vegetation Dynamics (Succession)



A gridcell in the northern hardwood forest of Northeast US (42°N, 74°W)

LSM-DGVM simulations

Like in the Hubbard Brook study, grasses dominate initially, followed by boreal deciduous trees. These then decline and temperate broadleaf deciduous trees dominate by 100 yrs. Boreal needleaf evergreen trees maintain low coverage, peaking at 20 yrs and then declining.

Observed community composition of Hubbard Brook: sugar maple, American beech, and yellow birch are the principal tree species, with a small component of other temperate and boreal species.

Bonan et al. (2003); Fig. 24.22 Bonan (2008)

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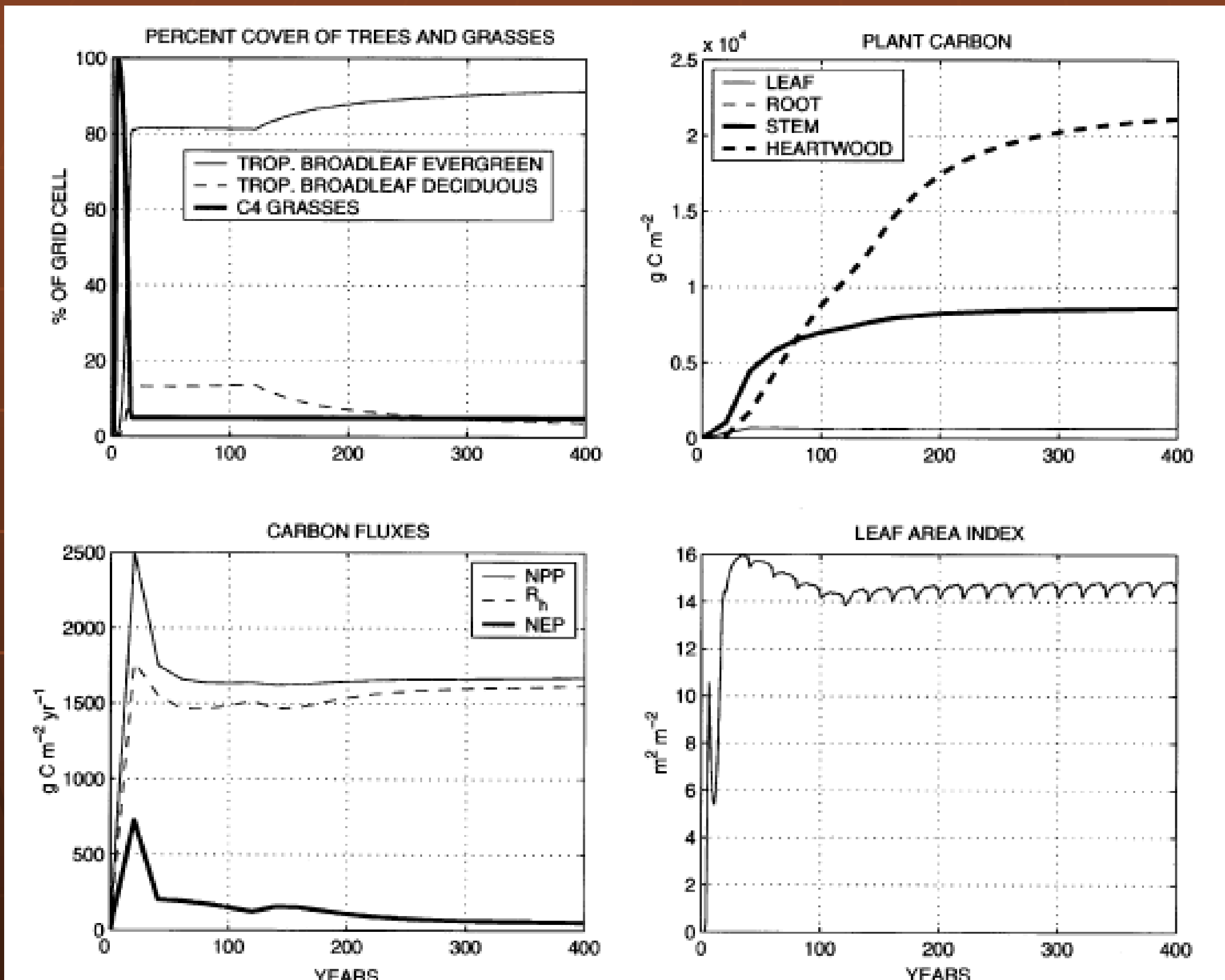
Vegetation Dynamics



A gridcell in the Amazon (5.0°S, 60.0°W)

LSM-DGVM simulations

Grasses dominate initially, reaching peak values after 5 years.

Tropical broadleaf evergreen trees gain dominance rapidly, reaching 81% coverage by 17 years.

This simulated growth is similar to an observed succession in tropical rainforests: rapid but short-lived coverage of weedy herbaceous plants following large-scale disturbance. Pioneer trees establish within a few years, replaced by slower-growing, longer-lived species which dominate after 20 years.

Bonan et al. (2003)

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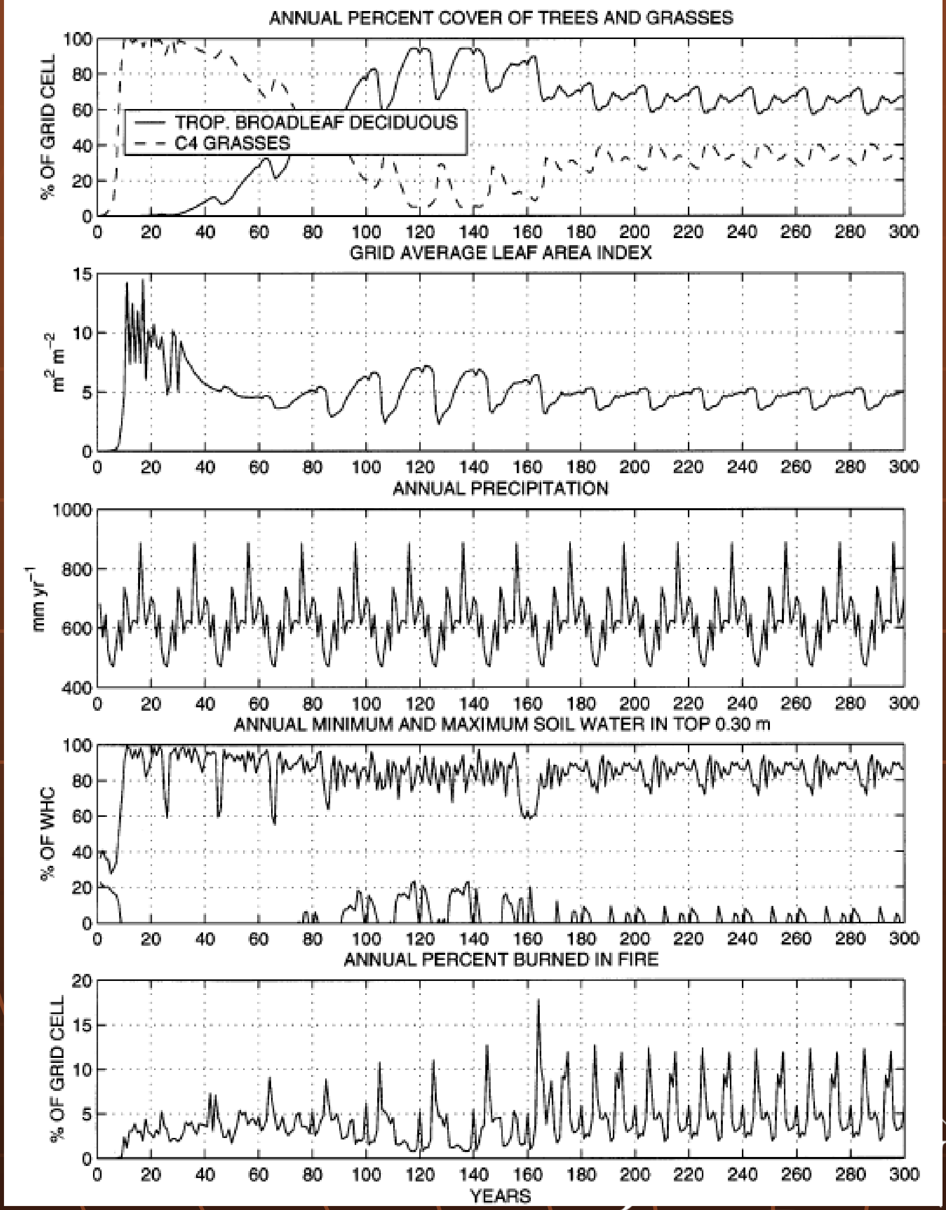
Vegetation Dynamics



A gridcell in African savanna (13.5°N, 7.5°W)

LSM-DGVM simulations

Grasses initially dominate, reaching 100% after 10-30 yrs, then decline as trees increase.
Trees dominate after 80 yrs, reaching maximum between 120-160 yrs. At yr 164, trees decline.

Importance of fire:
At yr 164, a large fire is triggered and burns 18% of the gridcell.

Fires: sporadic before yr 164, and regular after yr 164. Linked to appropriate annual minimum and maximum near-surface soil water and fuel load (woody and grassy mass)

Bonan et al. (2003); Fig. 24.22 Bonan (2008)

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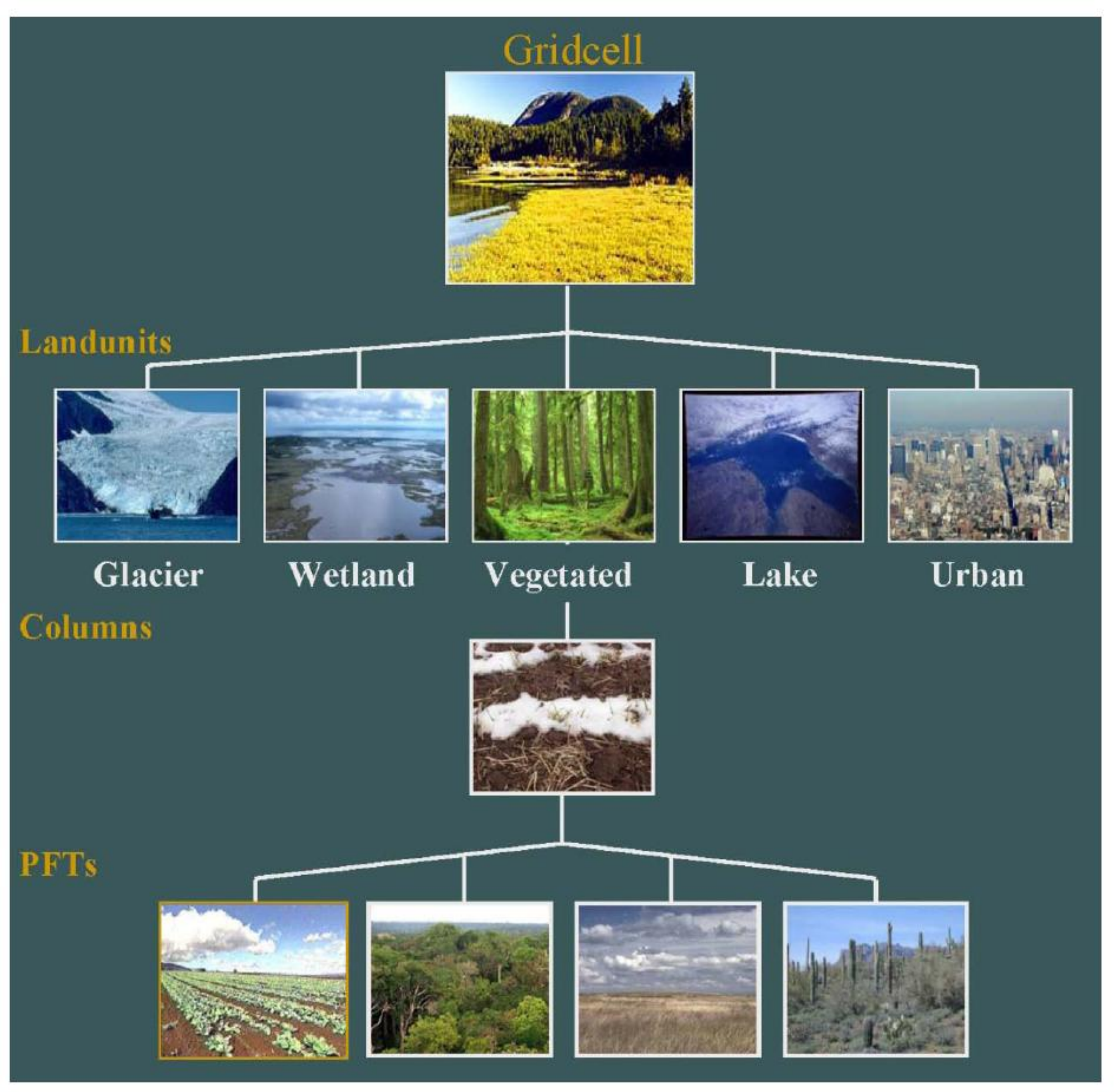
Subgrid Land Features in CLM4



Land is highly heterogeneous.

Representing sub-grid-scale land features has been a challenge.

Methods: a) mosaic or tiled approaches (see left); b) fine-mesh approaches (retaining geographic positions); c) aggregated parameters; d) statistical distributions of parameters.

CLM4 uses a hierarchy of three sub-grid levels. 1) A land grid cell has up to five landunits. 2) A landunit has ≥ 1 columns (e.g., 5-L snow/15-L soil columns). 3) A column has up to 16 pfts + 1 bare ground.

Landunits = glacier, lake, wetland, vegetated (all having a single soil column) and urban (5 columns).

Vegetated landunit = natural + managed (irrigated, non-irrigated).

Oleson et al. (2010)

CLM4 Plant Functional Types

Plant functional type	Acronym
Needleleaf evergreen tree – temperate	NET Temperate
Needleleaf evergreen tree - boreal	NET Boreal
Needleleaf deciduous tree – boreal	NDT Boreal
Broadleaf evergreen tree – tropical	BET Tropical
Broadleaf evergreen tree – temperate	BET Temperate
Broadleaf deciduous tree – tropical	BDT Tropical
Broadleaf deciduous tree – temperate	BDT Temperate
Broadleaf deciduous tree – boreal	BDT Boreal
Broadleaf evergreen shrub - temperate	BES Temperate
Broadleaf deciduous shrub – temperate	BDS Temperate
Broadleaf deciduous shrub – boreal	BDS Boreal
C_3 arctic grass	-
C_3 grass	-
C_4 grass	-
Crop1	-
[1]Crop2	-

[1]Two types of crops are allowed to account for the different physiology of crops, but currently only the first crop type is specified in the surface dataset.

Plant functional type	z_{top} (m)	z_{bot} (m)
NET Temperate	17	8.5
NET Boreal	17	8.5
NDT Boreal	14	7
BET Tropical	35	1
BET temperate	35	1
BDT tropical	18	10
BDT temperate	20	11.5
BDT boreal	20	11.5
BES temperate	0.5	0.1
BDS temperate	0.5	0.1
BDS boreal	0.5	0.1
C_3 arctic grass	0.5	0.01
C_3 grass	0.5	0.01
C_4 grass	0.5	0.01
Crop1	0.5	0.01
Crop2	0.5	0.01

Oleson et al. (2010)

Vegetation Optical Properties

Table 3.1. Plant functional type optical properties

Plant Functional Type	χ_L	α_{vis}^{leaf}	α_{nir}^{leaf}	α_{vis}^{stem}	α_{nir}^{stem}	τ_{vis}^{leaf}	τ_{nir}^{leaf}	τ_{vis}^{stem}	τ_{nir}^{stem}
NET Temperate	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
NET Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
NDT Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
BET Tropical	0.10	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BET temperate	0.10	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT tropical	0.01	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT temperate	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDT boreal	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BES temperate	0.01	0.07	0.35	0.16	0.39	0.05	0.10	0.001	0.001
BDS temperate	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
BDS boreal	0.25	0.10	0.45	0.16	0.39	0.05	0.25	0.001	0.001
C_3 arctic grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
C_3 grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
C_4 grass	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
Crop1	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250
Crop2	-0.30	0.11	0.35	0.31	0.53	0.05	0.34	0.120	0.250

Oleson et al. (2010)

Snow/Soil Optical Properties

Table 3.2. Intercepted snow optical properties

	Waveband (Λ)	
Parameter	vis	nir
ω^{sno}	0.8	0.4
β^{sno}	0.5	0.5
β_0^{sno}	0.5	0.5

Table 3.3. Dry and saturated soil albedos

	Dry		Saturated			Dry		Saturated	
Color Class	vis	nir	vis	nir	Color Class	vis	nir	vis	nir
1	0.36	0.61	0.25	0.50	11	0.24	0.37	0.13	0.26
2	0.34	0.57	0.23	0.46	12	0.23	0.35	0.12	0.24
3	0.32	0.53	0.21	0.42	13	0.22	0.33	0.11	0.22
4	0.31	0.51	0.20	0.40	14	0.20	0.31	0.10	0.20
5	0.30	0.49	0.19	0.38	15	0.18	0.29	0.09	0.18
6	0.29	0.48	0.18	0.36	16	0.16	0.27	0.08	0.16
7	0.28	0.45	0.17	0.34	17	0.14	0.25	0.07	0.14
8	0.27	0.43	0.16	0.32	18	0.12	0.23	0.06	0.12
9	0.26	0.41	0.15	0.30	19	0.10	0.21	0.05	0.10
10	0.25	0.39	0.14	0.28	20	0.08	0.16	0.04	0.08

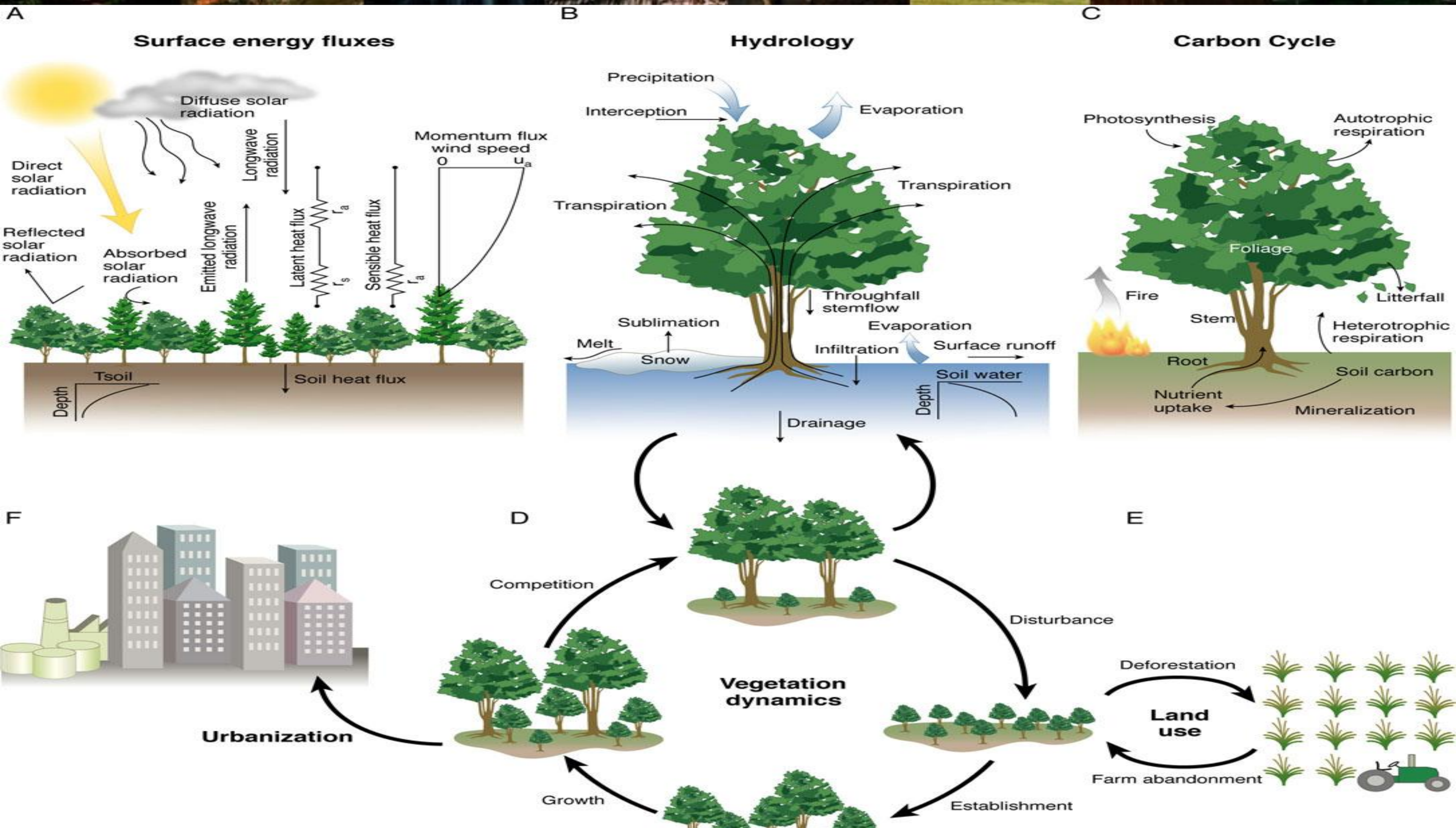
Oleson et al. (2010)

Scaling Up

http://www.chrisjordan.com/gallery/rtn2/#gyre

It takes a pretty picture to reveal an ugly reality.

NCAR Community Land Model (CLM4) for Climate Models in 2010



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CLM4

- Evolved from CLM3.5 (released in 2008). CLM3.5 improves over CLM3 (released in 2004)
  - Surface runoff (Niu, Yang et al., 2005)
  - Groundwater (Niu, Yang, et al., 2007)
  - Frozen soil (Niu and Yang, 2006)
  - Canopy integration, canopy interception scaling, and pft-dependency of the soil stress function
- CLM4 (released in 2010) improves over CLM3.5
  - Prognostic in carbon and nitrogen (CN) as well as vegetation phenology; the dynamic global vegetation model is merged with CN
  - Transient landcover and land use change capability
  - Urban component
  - BVOC component (MEGAN2)
  - Dust emissions
  - Updated hydrology and ground evaporation
  - New density-based snow cover fraction, snow burial fraction, snow compaction
  - Improved permafrost scheme: organic soils, 50-m depth (5 bedrock layers)
  - Conserving global energy by separating river discharge into liquid and ice water streams

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