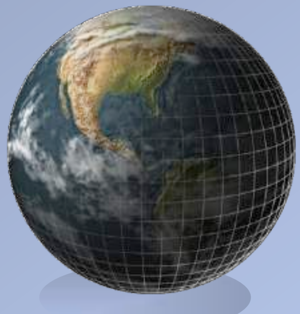
The Integrated BIosphere Simulator (IBIS) Version 2-- Overview and Philosophy



Center for Sustainability and the Global Environment, Institute for Environmental Studies
University of Wisconsin, Madison

Life before IBIS

3 different classes of models:

- *Land surface models* (SVATs): BATS, SiB, LSX, LSM, etc.

- *Biogeography models*: BIOME, MAPPS, etc.

- *Terrestrial biogeochemistry models*: TEM, CENTURY, CASA, BGC, DEMETER, etc.

Past Model Characteristics

- *Land surface models* -- fixed vegetation, limited biogeochemistry
- *Biogeography models* -- limited energy & water balance, limited biogeochemistry
- *Biogeochemistry models* -- fixed vegetation, limited energy & water balance

Can we build one model that integrates all these different processes and more?

IBIS global terrestrial ecosystem model

Links Processes Across Different Time Scales

"Fast" responses

- *Land surface processes*: fluxes of energy, water, momentum
- *Canopy physiology*: photosynthesis, respiration

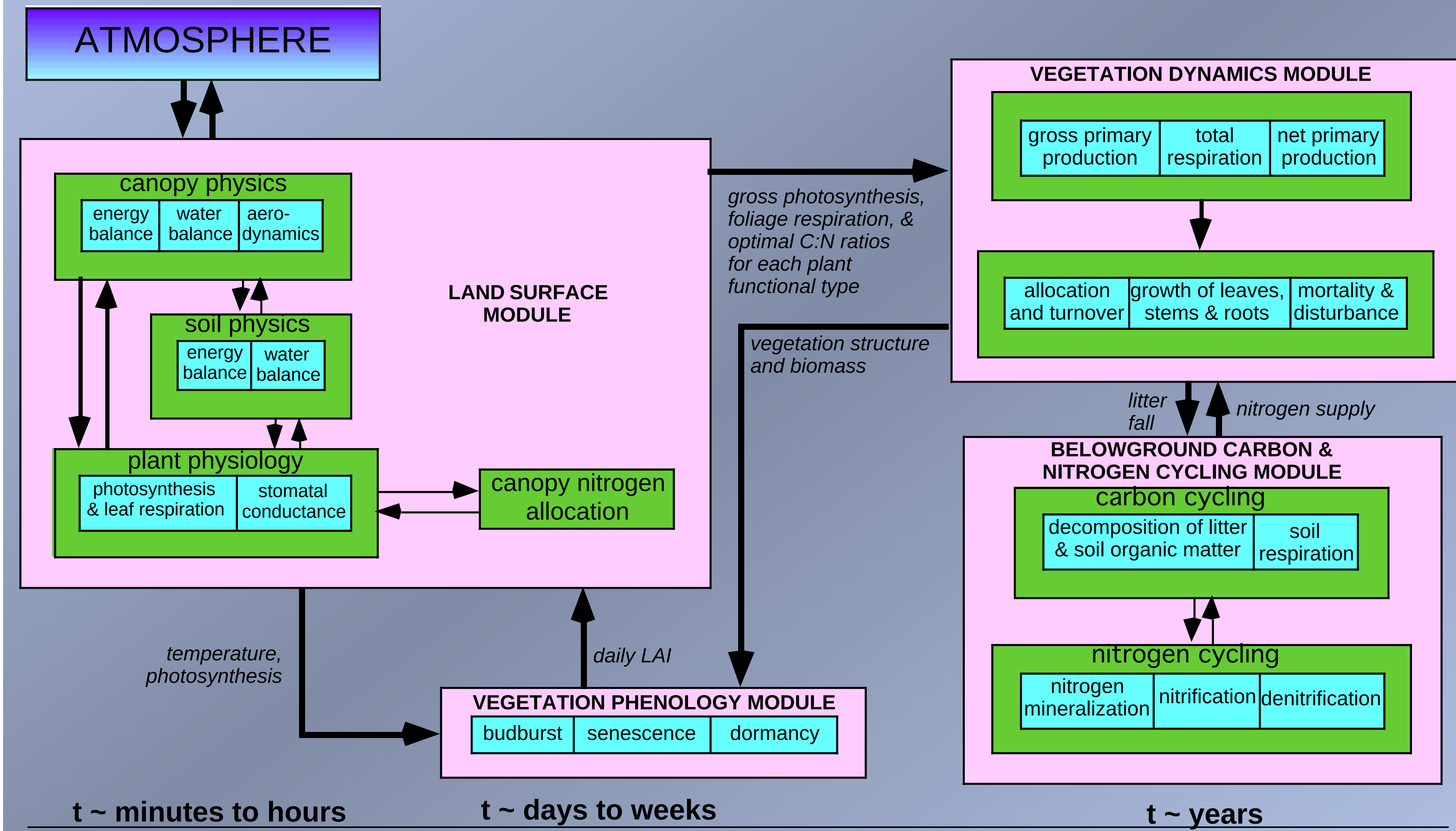
"Medium" processes

- *Vegetation phenology*: leafout, senescence, dormancy

"Slow" processes

- *Vegetation growth* (transient vegetation dynamics)
- *Above & below-ground carbon & nitrogen cycling*

Integrated Biosphere Simulator (IBIS)-2



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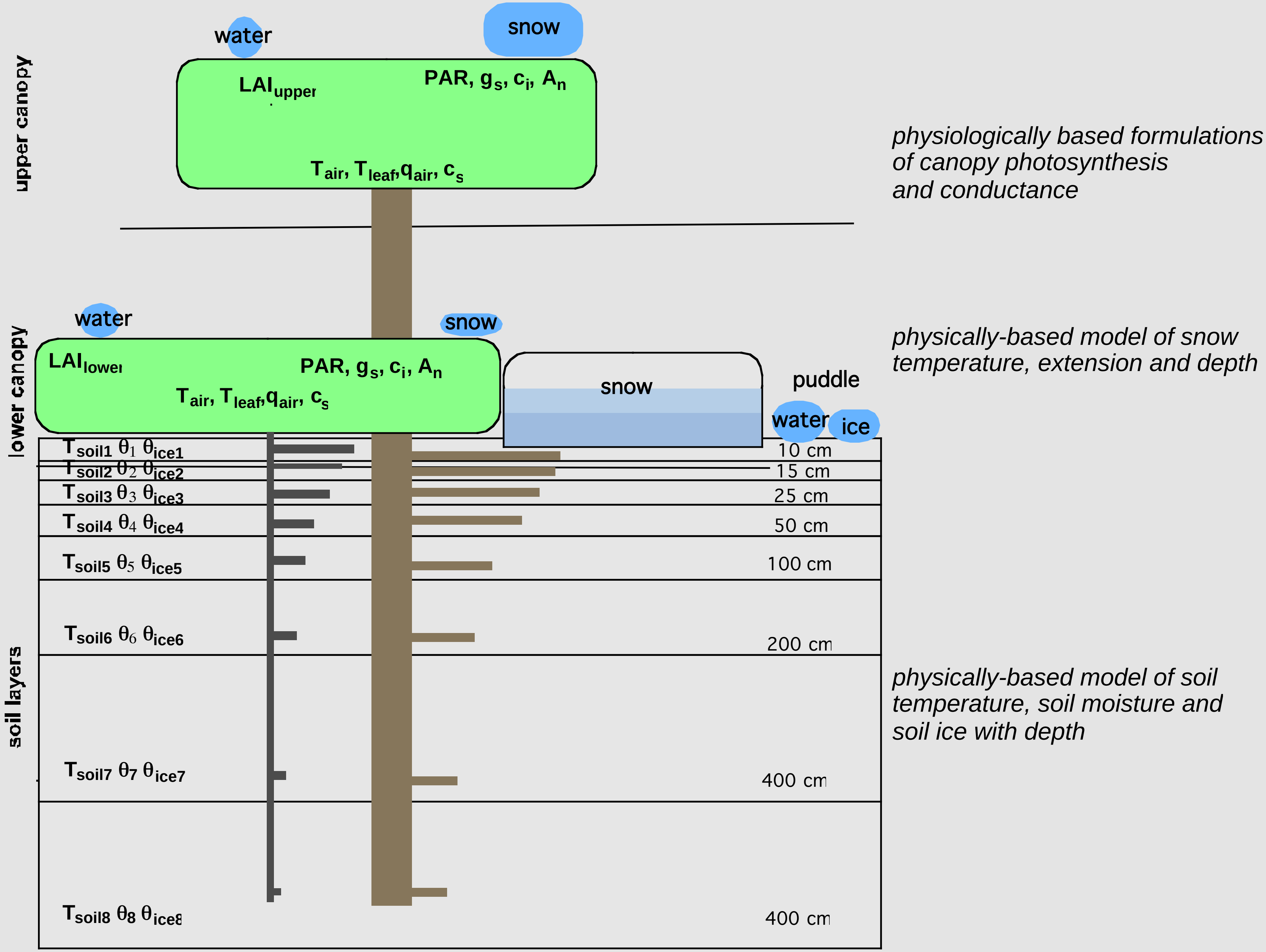


upper canopy
water
snow
LAIupper
PAR, gs, ci, An
Tair, Tleaf, qair, cs
physiologically based formulations
of canopy photosynthesis
and conductance
lower canopy
water
snow
LAIlower
PAR, gs, ci, An
Tair, Tleaf, qair, cs
snow
puddle
water
ice
physically-based model of snow
temperature, extension and depth
soil layers
Tsoil1 θ1 θice1
Tsoil2 θ2 θice2
Tsoil3 θ3 θice3
Tsoil4 θ4 θice4
Tsoil5 θ5 θice5
Tsoil6 θ6 θice6
Tsoil7 θ7 θice7
Tsoil8 θ8 θice8
10 cm
15 cm
25 cm
50 cm
100 cm
200 cm
400 cm
400 cm
physically-based model of soil
temperature, soil moisture and
soil ice with depth

Figure 2

IBIS Formulations

- *Canopy physics*:
  - Solar & Infrared radiative transfer
  - Two-stream approximation
  - Diffusive & turbulent fluxes of heat and water vapor through canopy and soils (including soil ice)
  - Wind speeds through the canopy
- *Soil physics*
  - Water, ice (Richard's equation)
  - Darcy's Law for vertical water flux

IBIS Formulations

- *Canopy physiology*:
  - Mechanistic photosynthesis (Farquhar et al. 1980)
    - Light and water limitations
  - Semi-mechanistic stomatal conductance (Ball & Berry)
  - Coupled photosynthesis-stomatal conductance model (Collatz et al. 1991)
    - => coupled flow of carbon & water
  - Canopy scaling (APAR within canopy for net assimilation)

IBIS Formulations

- *Canopy phenology*:
  - Budburst and litterfall of winter-deciduous plants based on climatic limits, constraints, accumulated GDD
  - Drought deciduous plants respond to net canopy carbon budget

IBIS Formulations

- Vegetation Dynamics:
  - 12 Plant Functional Types (PFTs)
    - 8 in upper canopy (trees)
    - 4 in lower canopy (shrubs and cool/warm grasses)
  - Compete for light & water
    - LAI - Shading - radiation; root profiles
  - Competition is a consequence of the annual carbon balance
  - Geographic distribution
    - Cold tolerance limits, growing degree-day requirements, and minimum chilling requirements

Description of IBIS-2 Plant Functional Types (PFTs)

Table 1.

Trees	m	b	$V_{m,15}$	T_{min}(°C)	T_{min}(°C)	GDD_5	σ, $m^2\ kg^{-1}$	a_{leaf}	a_{root}	a_{stem}	τ_{leaf} years	τ_{root} years	τ_{stem} years
Tropical broadleaf evergreen	10.0	0.01	65.0	> 0.0			25.0	0.30	0.20	0.50	1.00	1.0	25.0
Tropical broadleaf drought-deciduous	10.0	0.01	65.0	> 0.0			25.0	0.30	0.20	0.50	1.00	1.0	25.0
Temperate broadleaf evergreen	10.0	0.01	40.0	> -10.0	< 0.0		25.0	0.30	0.20	0.50	1.00	1.0	25.0
Temperate conifer evergreen	6.0	0.01	30.0	> -45.0	< 0.0	> 1200	12.5	0.30	0.40	0.30	2.00	1.0	50.0
Temperate broadleaf cold-deciduous	10.0	0.01	30.0	> -45.0	< 0.0	> 1200	25.0	0.30	0.20	0.50	1.00	1.0	50.0
Boreal conifer evergreen	6.0	0.01	25.0	> -57.5	< -45.0*	> 350	12.5	0.30	0.40	0.30	2.50	1.0	100.0
Boreal broadleaf cold-deciduous	10.0	0.01	30.0	> -57.5	< -45.0*	> 350	25.0	0.30	0.20	0.50	1.00	1.0	100.0
Boreal conifer cold-deciduous	10.0	0.01	30.0		< -45.0*	> 350	25.0	0.30	0.20	0.50	1.00	1.0	100.0

Shrubs and Grasses	m	b	$V_{m,15}$	T_w(°C)		GDD_0	σ, $m^2\ kg^{-1}$	a_{leaf}	a_{root}	a_{stem}	τ_{leaf} years	τ_{root} years	τ_{stem} years
Evergreen shrub	9.0	0.01	27.5			> 100	12.5	0.45	0.40	0.15	1.50	1.0	5.0
Cold-deciduous shrub	9.0	0.01	27.5			> 100	25.0	0.45	0.35	0.20	1.00	1.0	5.0
Cool grass	9.0	0.01	25.0			> 100	20.0	0.45	0.55	0.00	1.50	1.0	n /a
Warm grass	4.0	0.04	15.0	> 22.0		> 100	20.0	0.45	0.55	0.00	1.25	1.0	n /a

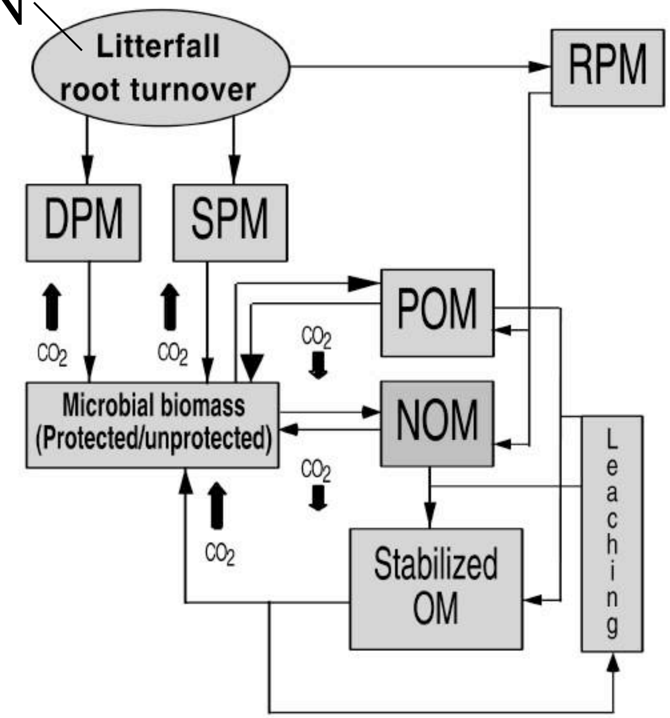
Foley et al., 1996; Kucharik et al., 2000 *Global Biogeochemical Cycles*

IBIS Formulations

- *Soil biogeochemistry*:
  - CENTURY-like model
  - Active microbial pool
  - Daily timestep

IBIS Soil Biogeochemistry Submodel

C:N (roots 60, leaves 40, wood 200)



C Mineralized/CO_2 Released
N Immobilized/Mineralized

Litterfall for natural vegetation
Spread evenly (daily) across entire year

Figure 3

Litter Pools (above and belowground)
Turnover ~ days to weeks (k value)
DPM - decomposable plant material (C/N ~ 6)
SPM - Structural plant material (C/N ~ 100)
RPM - Resistant (lignin) plant material (C/N ~ 150)

Microbial Biomass (labile)
Turnover ~ weeks - months (k value)
C/N ~ 8-10

Slow C Pools (POM/NOM)
Turnover ~ 10-20 years (k value)
C/N ~ 10-12

Passive C Pools (stabilized/recalcitrant)
Turnover ~ 100s-1000s of years (k value)
C/N ~ 10-12

ADAPTED FROM KUCHARIK ET AL., 2000 - *GLOBAL BIOGEOCHEMICAL CYCLES*

A few other notes about the biogeochemistry model…

- Numerical acceleration is needed to establish equilibrium of C and N pools

- K values (decomposition constants) are modified by soil temperature (*Lloyd & Taylor*, 1994) and moisture (*Linn and Doran*, 1984); which influence microbial activity
  - Aboveground litter pool - surface layer
  - All other soil C pools by weighted average soil temperature and moisture (by root profile)
- We do not explicitly simulate soil C & N as a function of soil layer

- Current leaching values of DOC are more of a “fudge” so that C does not build up exponentially in soils

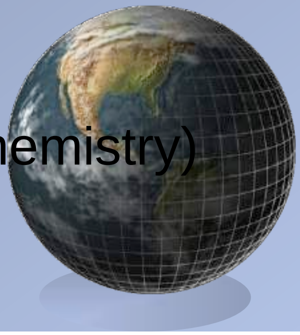
- Classes of microbes are not simulated; they are assumed to all behave similarly to soil T and moisture regardless of biome type

IBIS Implementation

- *Offline and coupled modes* (GCM)
  - Requires temperature, wind speed, radiation, humidity, precip
- *Hourly time step (normally)*
- *Climate data* – daily or monthly mean, gridded values
  - Climatology (30-yr average climate : 1981-2010)
  - Inter-annual variability (CRU: 1901-2007)
    - 0.5 degree resolution local to global scale
  - 8km x 8km resolution with ZedX daily climate dataset (1948-2007)
  - Weather generator used to get daily/sub-daily values

- *Soil data* (texture) as function of depth (IGBP - Global STATSGO - US) - lookup table for properties

- Mode: cold-start, dynamic vegetation, fixed vegetation
- Coupling to THMB (terrestrial hydrology model with biogeochemistry)



Examples of IBIS-2 Model Output

- From Kucharik et al., 2000 published in *Global Biogeochemical Cycles*

Present-day Climate - IBIS Simulated Potential Vegetation

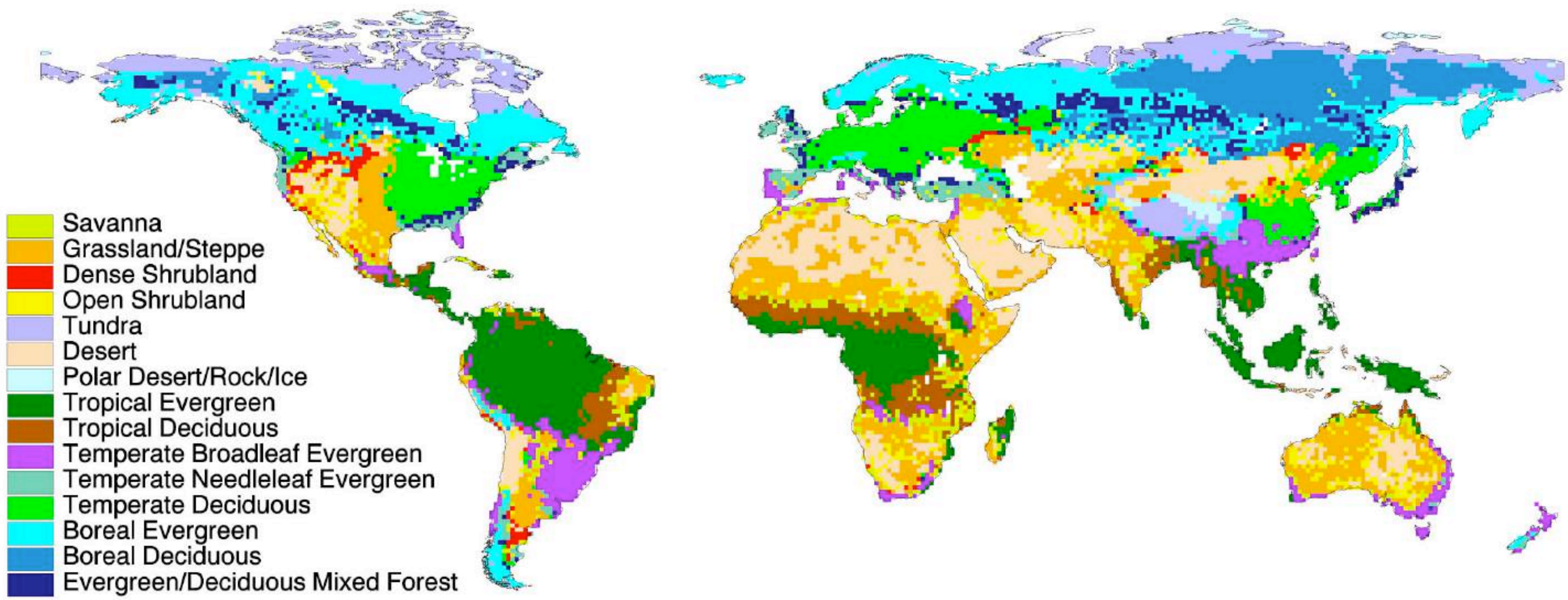


Plate 4c. Simulated Vegetation Types

From Kucharik et al., 2000 *Global Biogeochemical Cycles*

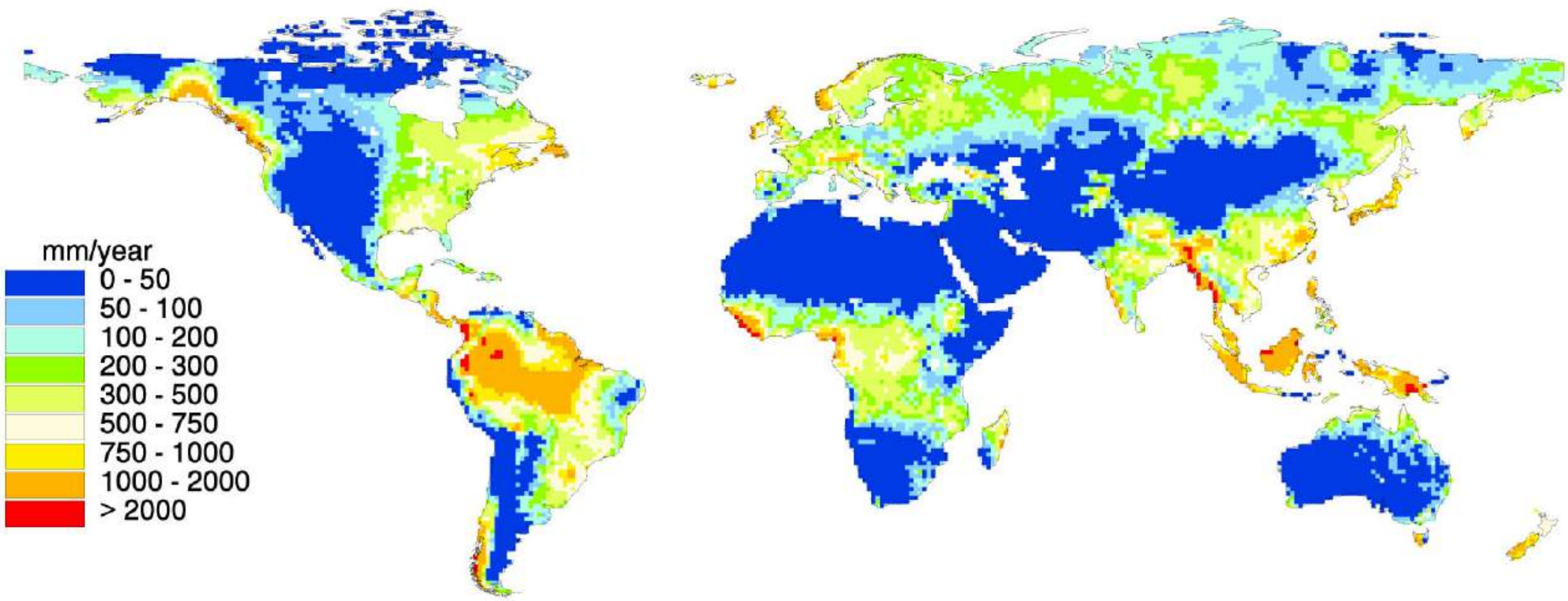
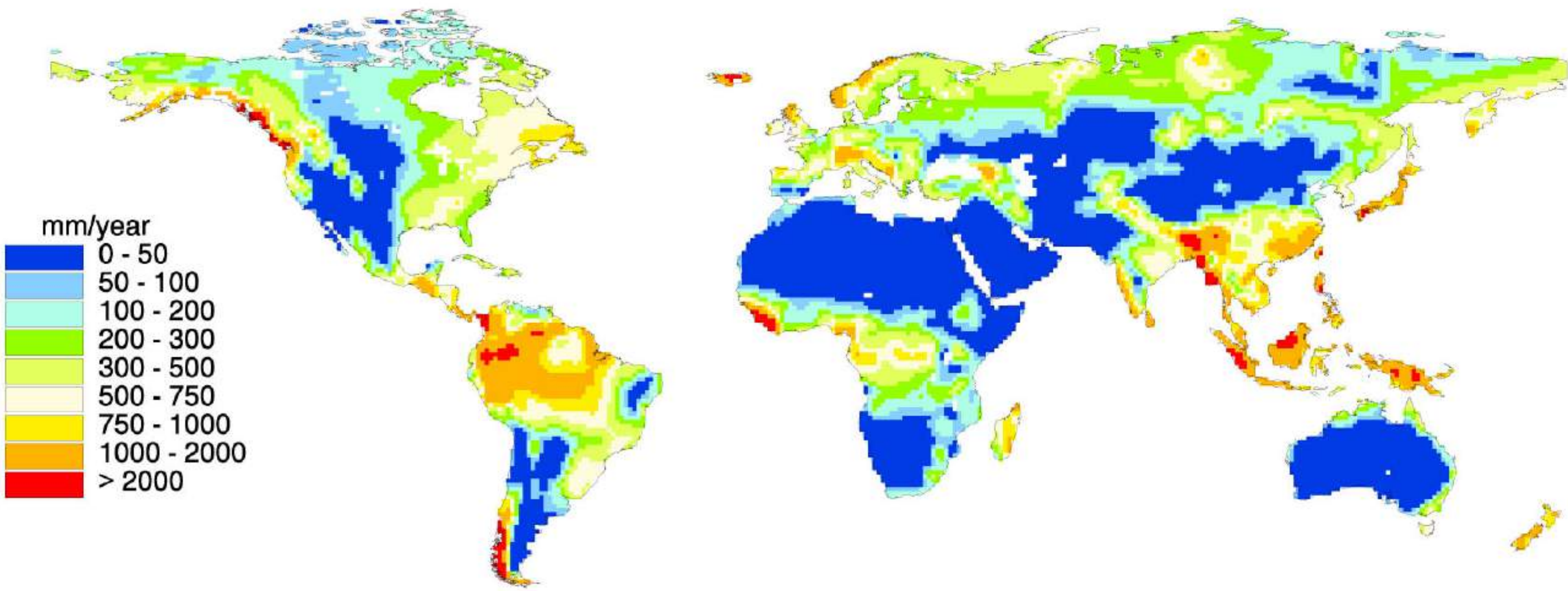
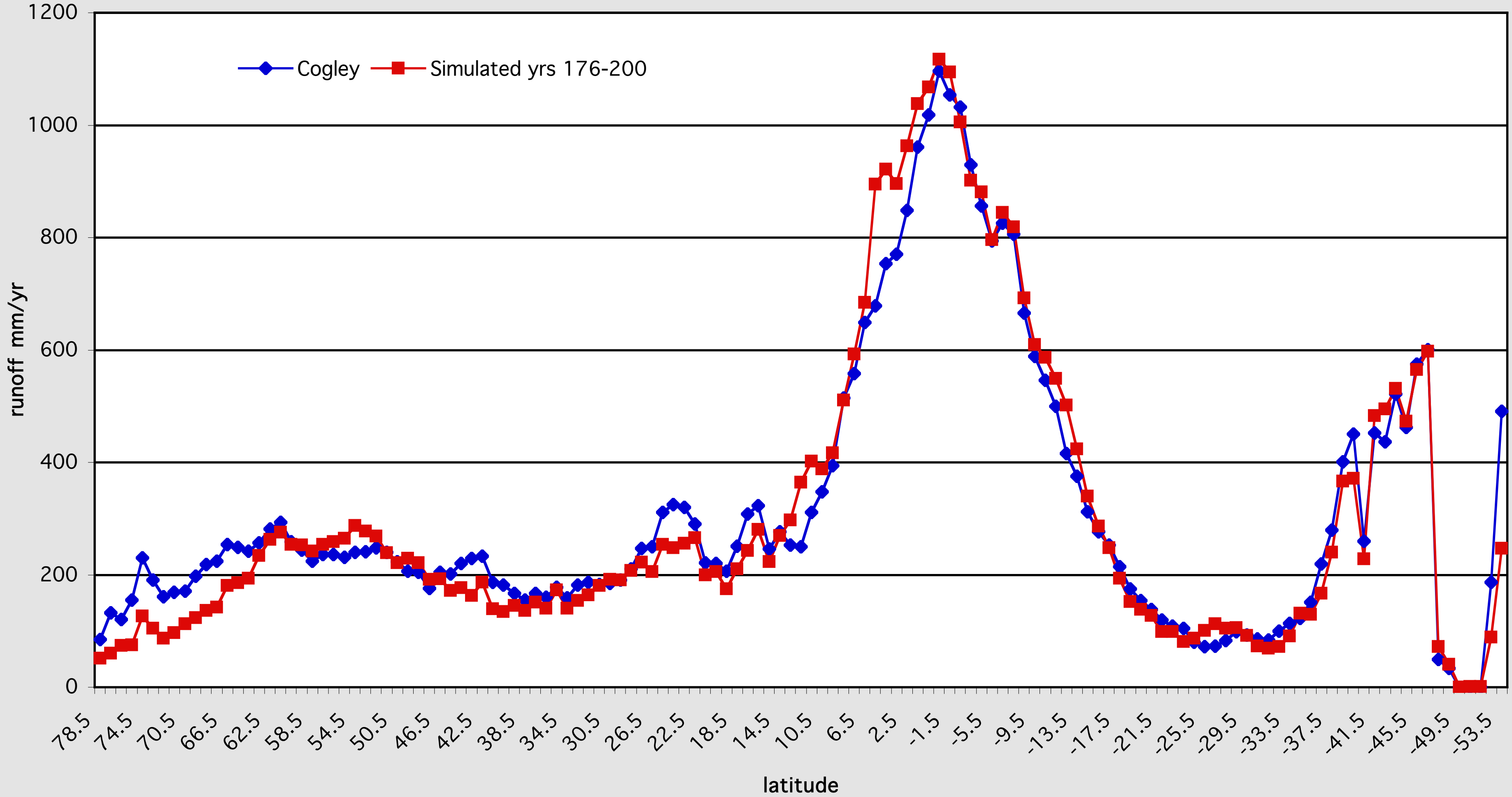


Plate 1a. Simulated Runoff



From Kucharik et al., 2000 *Global Biogeochemical Cycles*

Plate 1b. Observed Runoff



From Kucharik et al., 2000 *Global Biogeochemical Cycles*

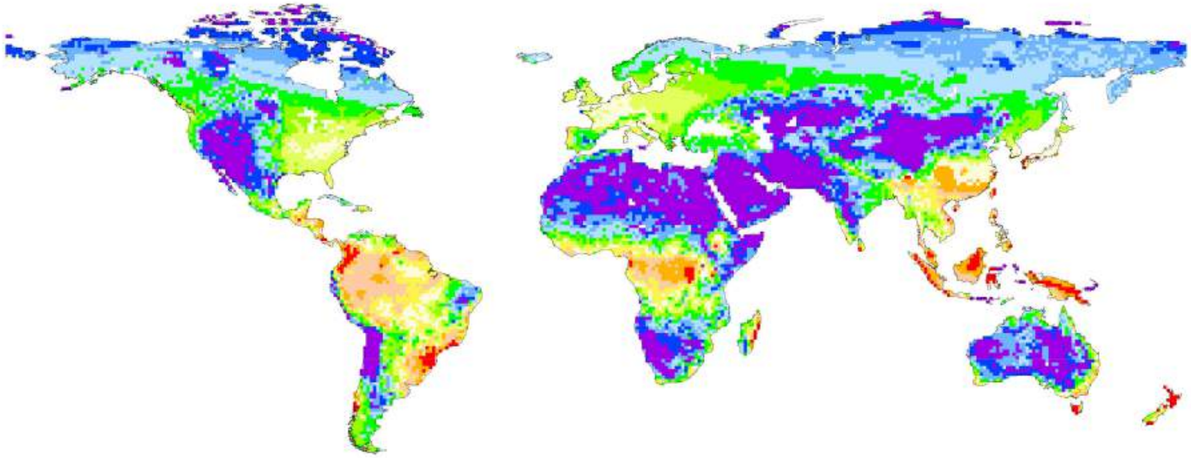


Plate 2a. Simulated NPP

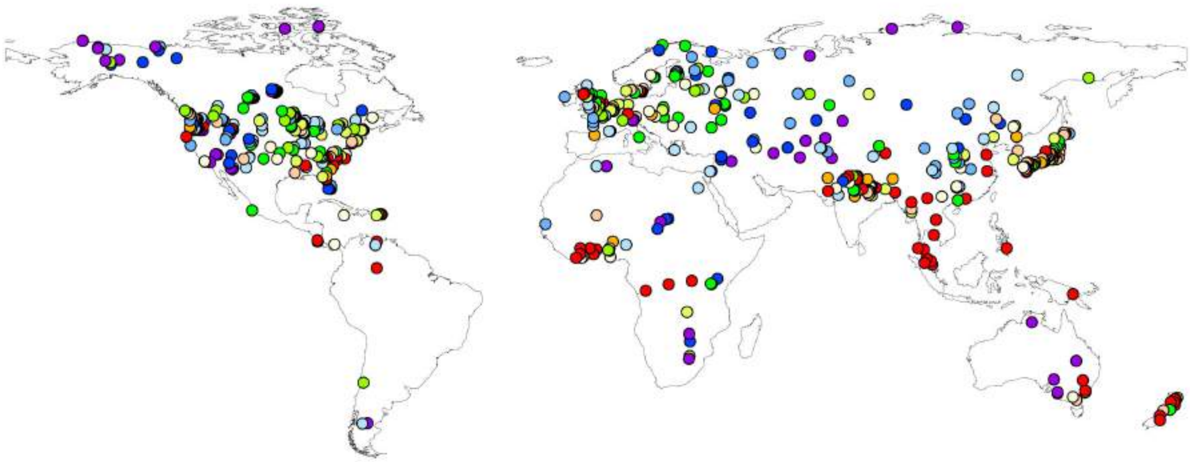
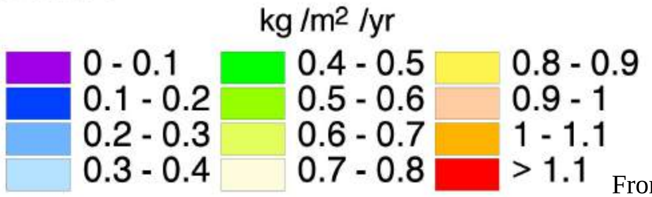


Plate 2b. Observed NPP



From Kucharik et al., 2000 *Global Biogeochemical Cycles*

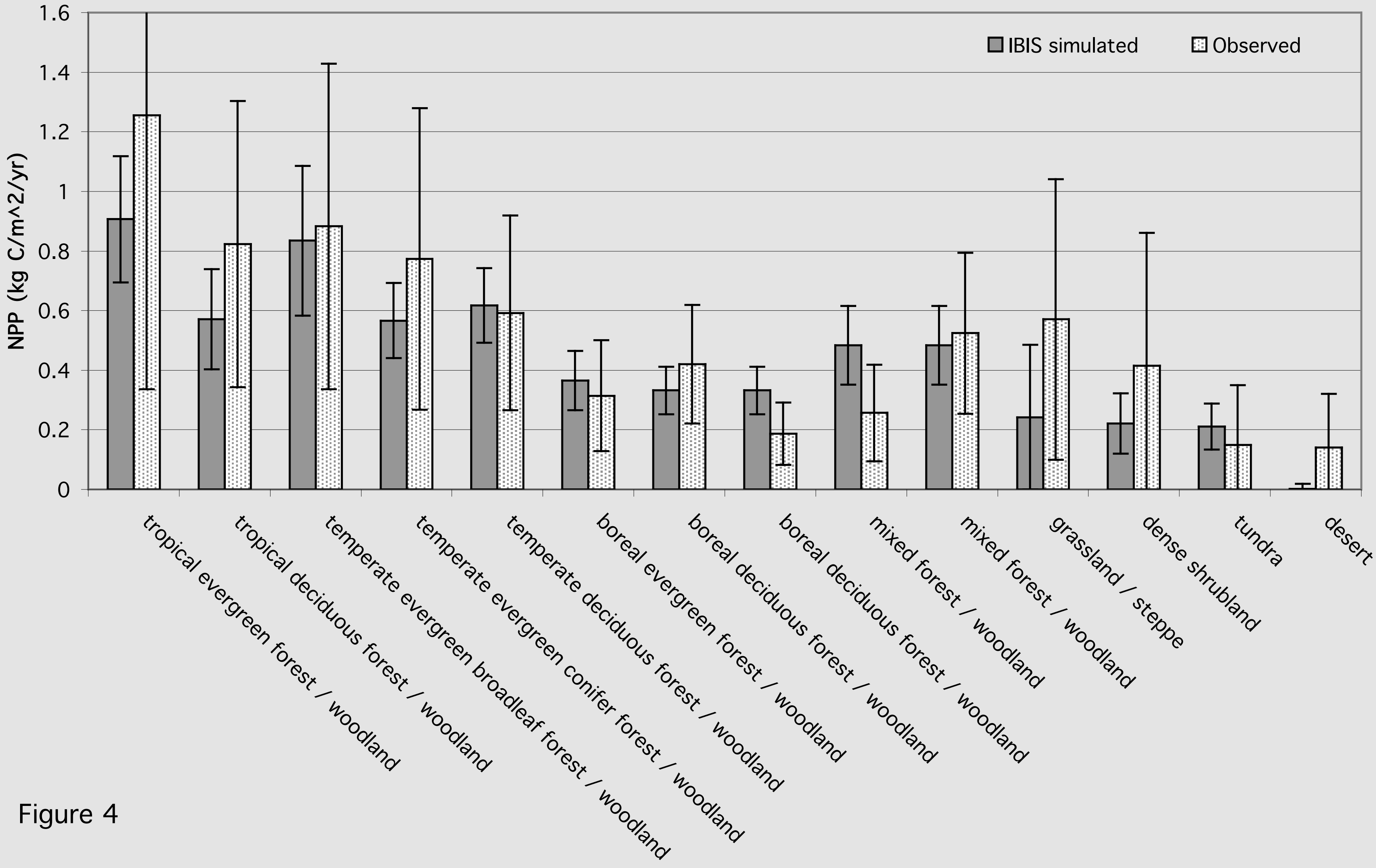


Figure 4

From Kucharik et al., 2000 *Global Biogeochemical Cycles*

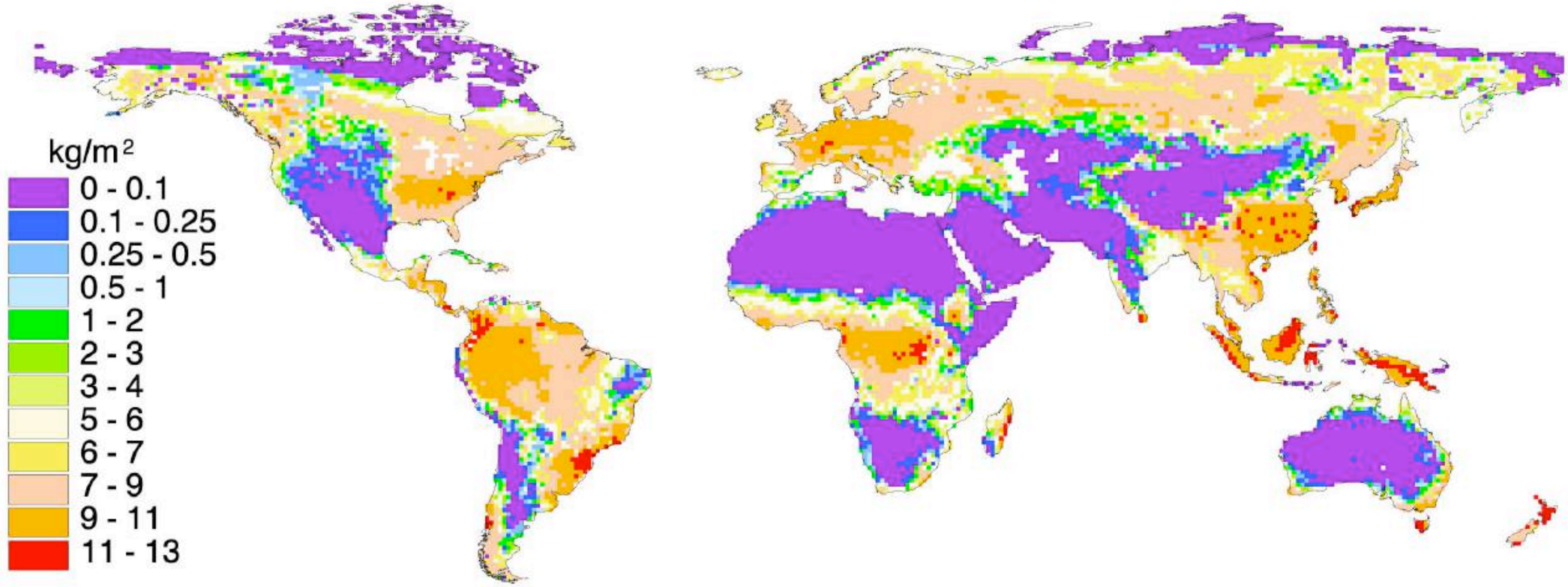


Plate 3a. Simulated Biomass of Trees

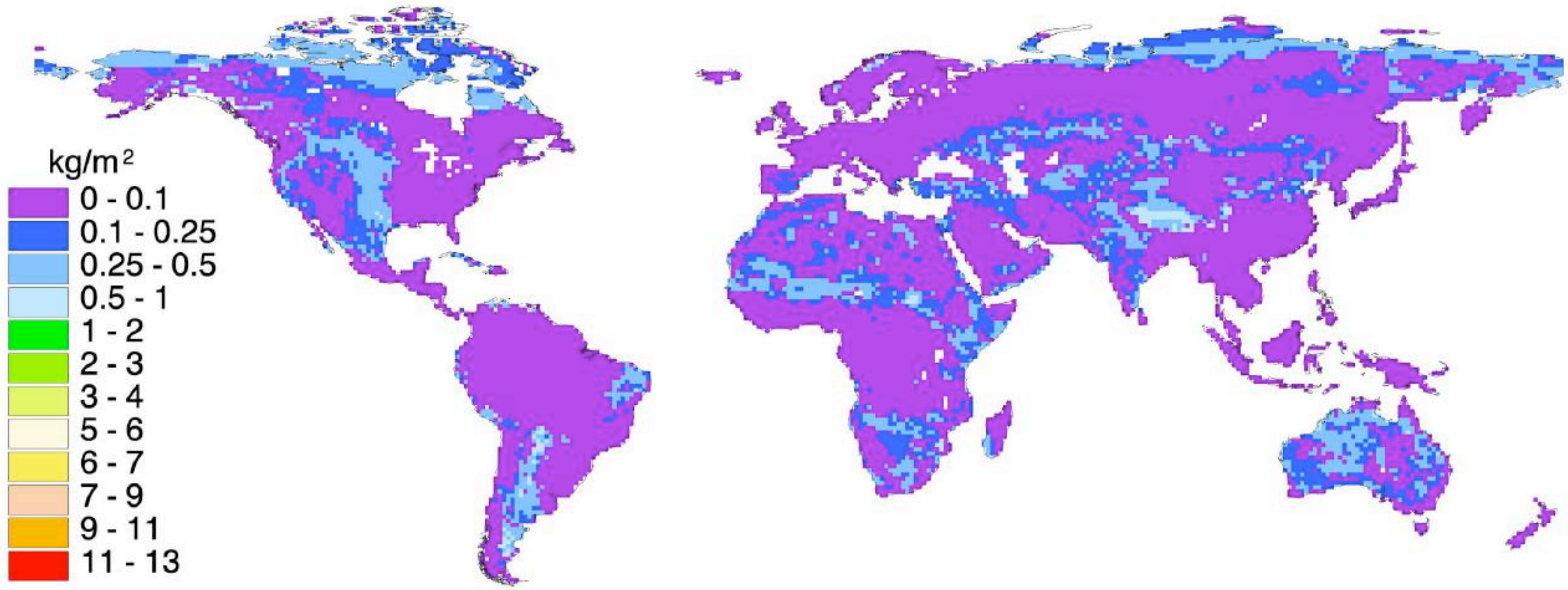


Plate 3b. Simulated Biomass of Grasses and Shrubs

From Kucharik et al., 2000 *Global Biogeochemical Cycles*

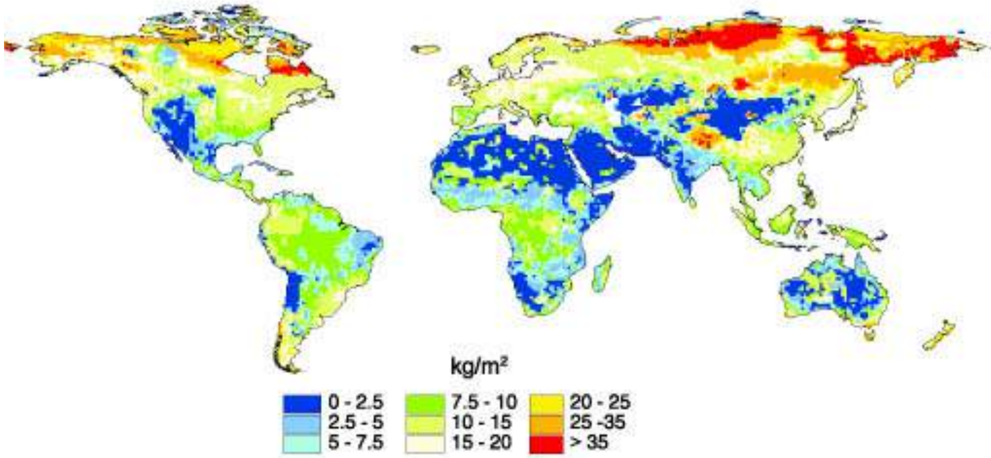


Plate 6a. Simulated Total Soil Carbon Density

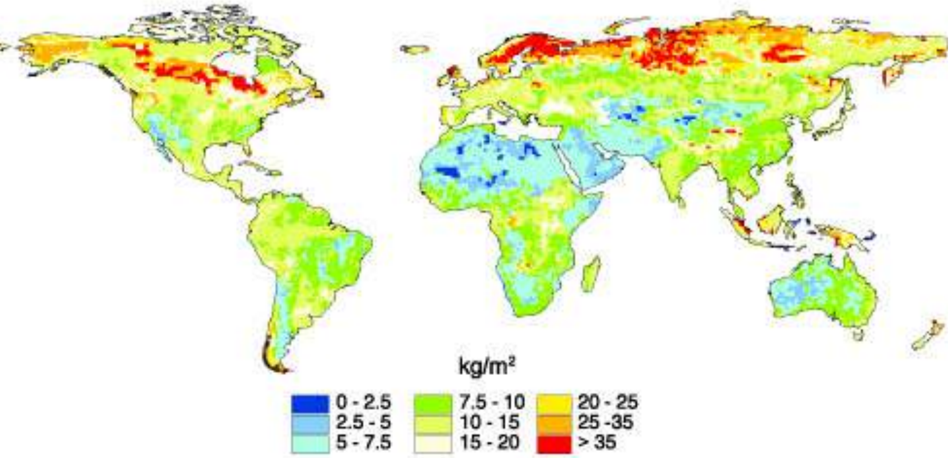


Plate 6b. Observed Soil Carbon Density

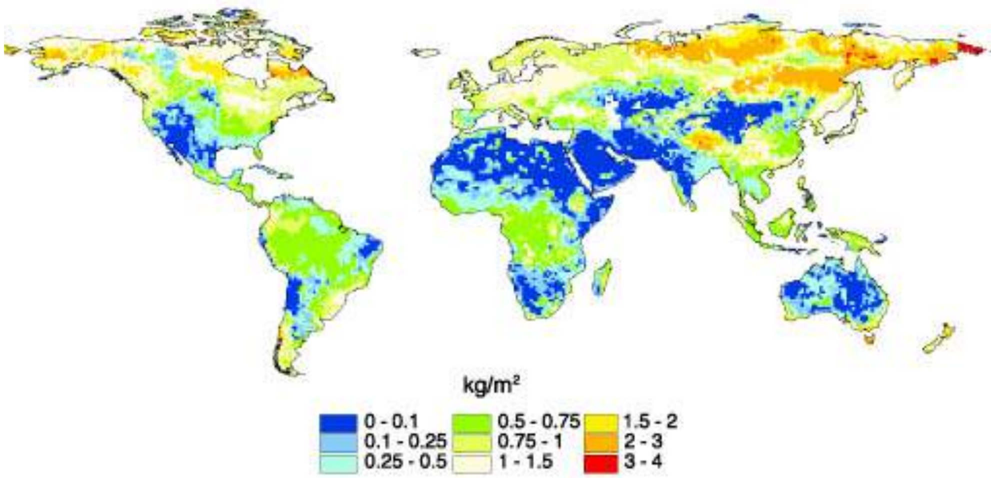


Plate 6d. Simulated Total Litter Carbon (Aboveground and Fine Root)

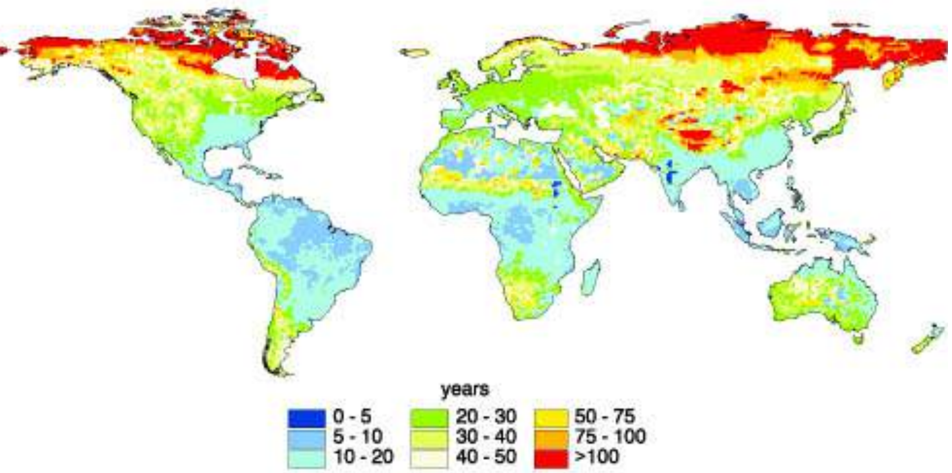
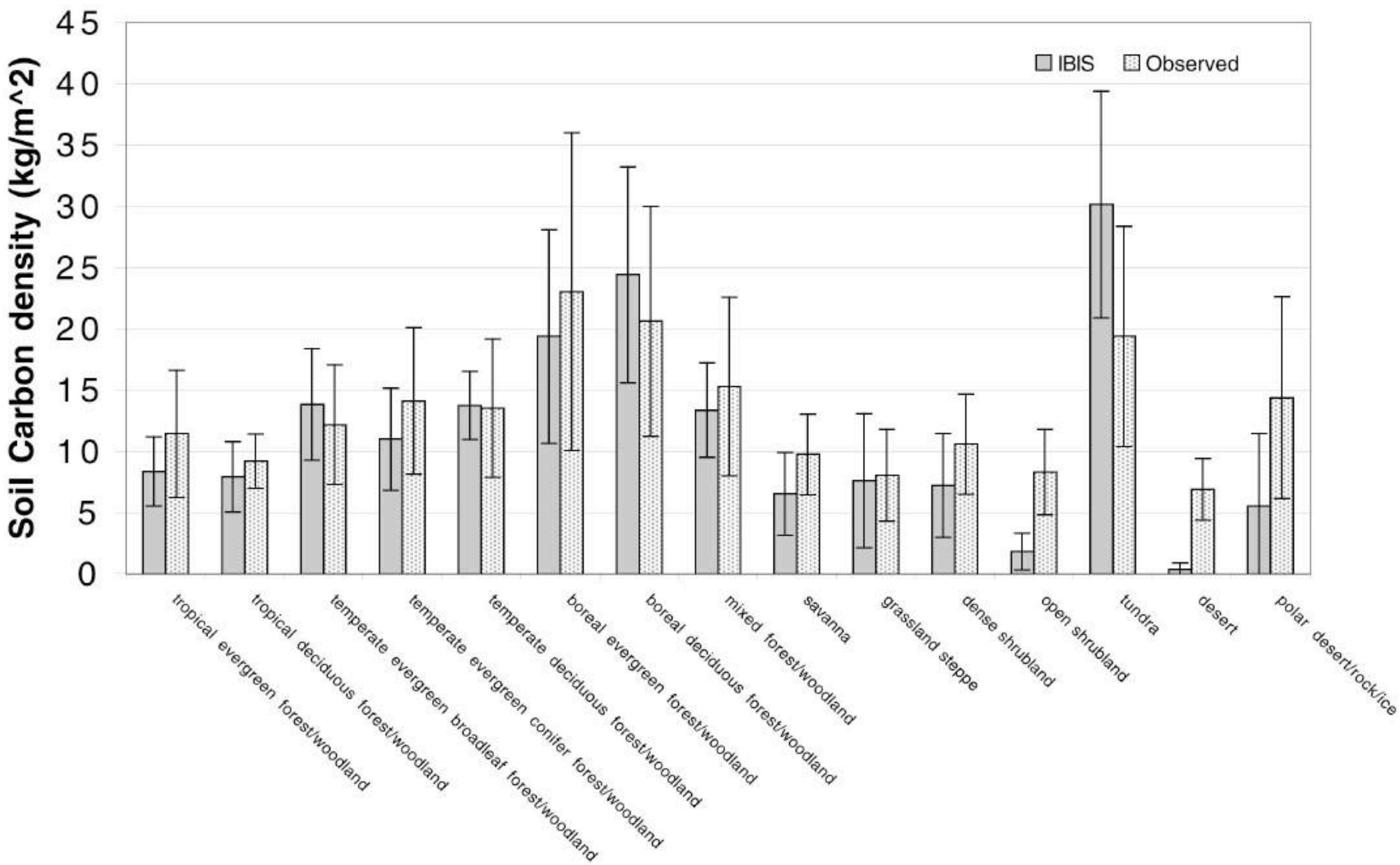


Plate 6d. Simulated Mean Carbon Residence Time in Litter and Soil Carbon

From Kucharik et al., 2000 *Global Biogeochemical Cycles*

Figure 6



From Kucharik et al., 2000 *Global Biogeochemical Cycles*

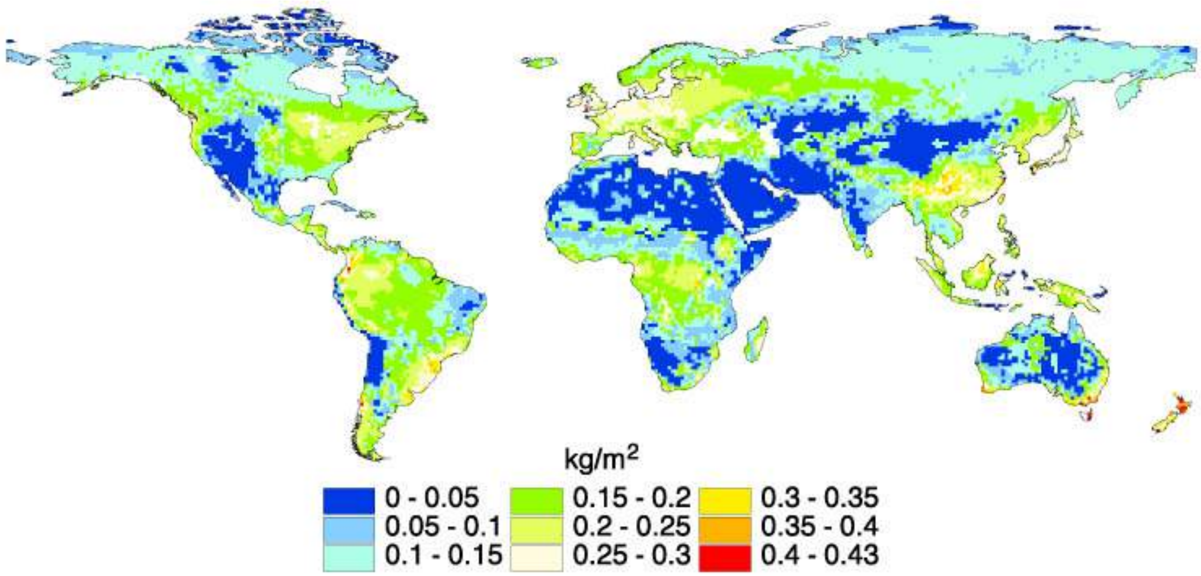
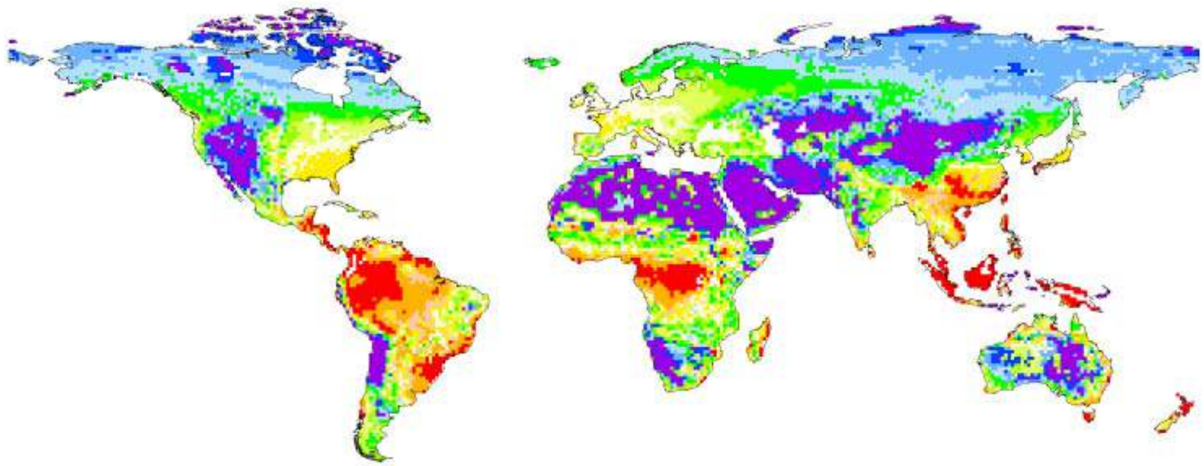


Plate 7a. Simulated Microbial Biomass Carbon



From Kucharik et al., 2000 *Global Biogeochemical Cycles*

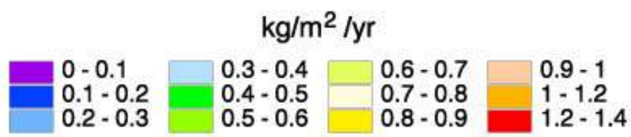


Plate 7b. Simulated Total Soil Carbon Respiration (Fine Root and Microbial)

IBIS-2 Annual Average Global Quantities for Contemporary Biosphere 1965-1994

Table 4.

Biome	Area,[1] 10^6 km^2	GPP, kg C m^{-2} yr^{-1}	NPP, kg C m^{-2} yr^{-1}	LAI, m^2 m^{-2}	Biomass, kg C m^{-2}	FRB, kg C m^{-2}	τ_{veg}, years	Litter, kg C m^{-2}	SOM, kg C m^{-2}	τ_{som}, years	MB, kg C m^{-2}	Soil CO_2, kg C m^{-2} yr^{-1}	NEE, kg C m^{-2} yr^{-1}
Tropical evergreen forest	19.30	1.89	0.90	6.8	9.1	0.18	10.0	0.60	9.5	11.2	0.20	1.15	0.037
Tropical deciduous forest	7.70	1.23	0.57	4.2	5.4	0.11	9.4	0.42	7.9	11.4	0.12	0.70	0.053
Temperate broadleaf evergreen forest	7.20	1.57	0.83	6.2	8.2	0.16	9.8	0.88	13.8	16.5	0.24	0.96	0.051
Temperate needleleaf evergreen forest	3.29	1.14	0.57	4.3	5.9	0.20	10.5	0.59	11.0	24.3	0.20	0.71	0.037
Temperate deciduous forest	9.67	1.14	0.62	4.6	8.3	0.16	13.5	0.81	13.7	23.1	0.21	0.66	0.049
Boreal evergreen forest	14.50	0.66	0.37	3.3	5.5	0.13	15.1	0.81	19.4	54.0	0.14	0.38	0.028
Boreal deciduous forest	6.80	0.55	0.33	2.7	6.2	0.08	18.5	1.33	24.4	80.5	0.12	0.29	0.026
Evergreen/deciduous mixed forest	4.23	0.91	0.48	3.8	7.6	0.14	15.8	0.89	13.4	35.8	0.17	0.50	0.039
Savanna	5.34	0.93	0.35	3.3	2.4	0.13	6.7	0.29	6.5	20.3	0.12	0.61	-0.016
Grassland/steppe	21.20	0.76	0.24	2.8	0.4	0.13	1.8	0.08	7.6	32.3	0.10	0.53	-0.005
Dense shrubland	1.50	0.44	0.22	2.2	0.9	0.08	4.2	0.41	7.2	37.8	0.09	0.27	0.025
Open shrubland	6.02	0.17	0.05	0.7	0.3	0.03	7.3	0.08	1.8	57.1	0.03	0.15	-0.040
Tundra	6.24	0.39	0.21	2.3	0.3	0.10	1.5	0.75	30.1	138.6	0.10	0.24	0.018
Desert	18.80	0.02	0.001	0.1	0.04	0.004	38.4	0.01	0.4	398.2	0.006	0.022	-0.013
Polar Desert/Rock/ice	0.83	0.02	0.02	0.2	0.03	0.007	1.7	0.11	5.5	143.1	0.007	0.017	0.002
Global Average		0.87	0.41	3.4	4.2	0.15	13.4	0.49	10.6	89.6	0.13	0.53	0.0174
	10^6 km^2	Gt C yr^{-1}	Gt C yr^{-1}		Gt C	Gt C		Gt C	Gt C		Gt C	Gt C yr^{-1}	Gt C yr^{-1}
Global Total	132.6[1]	114.7	54.3		557.4	15.2		65.0	1408.1		16.7	70.2	2.3

[1]We note that Greenland, part of the Canadian Archipelago and Antarctica are not included in IBIS simulations.

From Kucharik et al., 2000 *Global Biogeochemical Cycles*

What has IBIS-2 given us?

- An ecosystem modeling tool
  - Dynamic Global Ecosystem Model (DGEM)
- Capability to simulate vegetation competition - structure - function
- Global Water Balance
- Global Carbon Balance