Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests

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Outline

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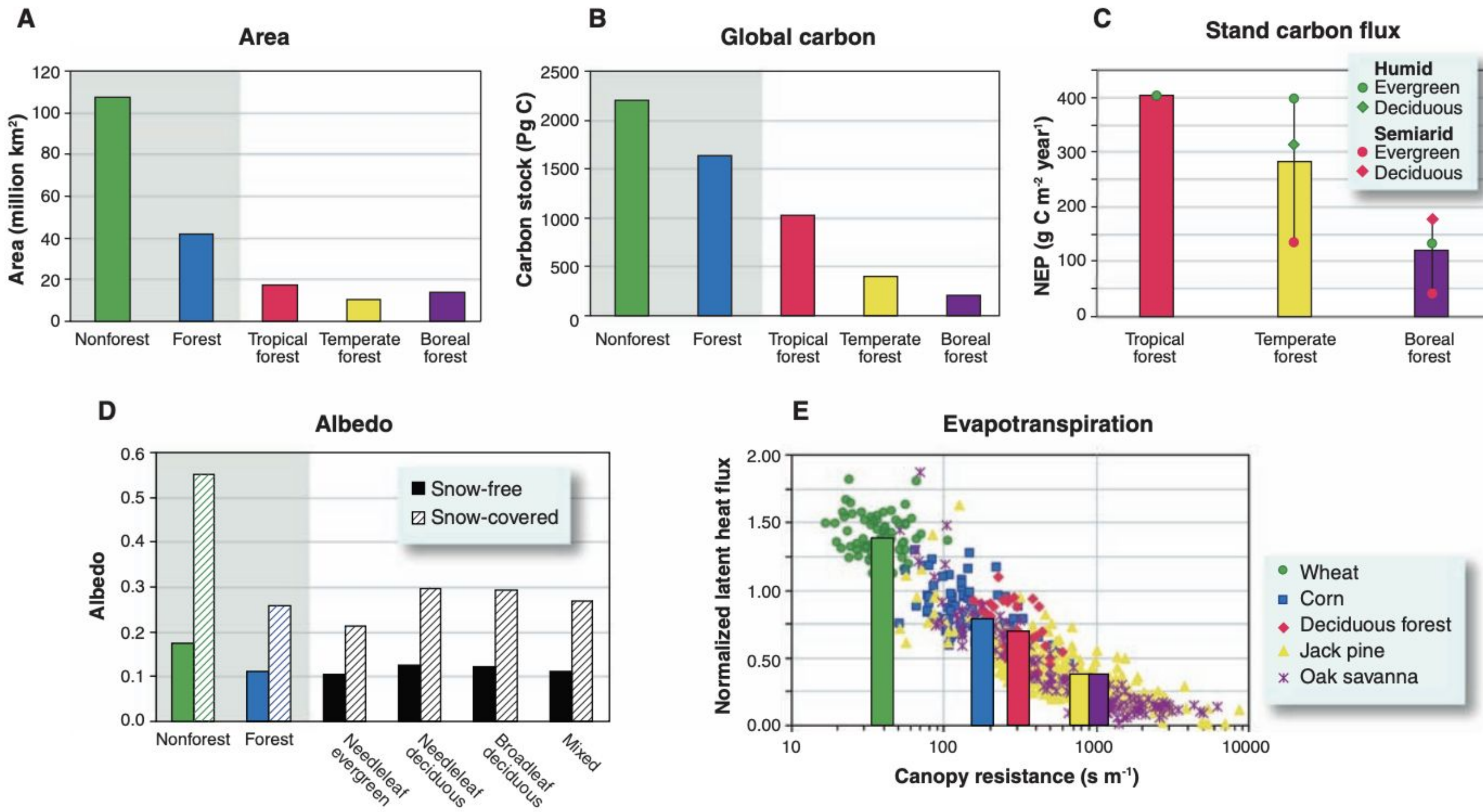
Purpose

- Reviews biosphere-atmosphere interactions in tropical, temperate, and boreal forests
  - emphasis placed on biogeophysical processes, albedo and evapotranspiration,
  - their comparison with biogeochemical processes, carbon cycle, and alteration of forest-atmosphere
  - through biogeographical processes, land use and vegetation dynamics

Importance

- World's forests influence climate through physical, chemical, and biological processes that affect the hydrologic cycle and atmospheric composition.
- Forest-atmospheric interactions can decrease or amplify anthropogenic climate change through carbon sequestration and biogeophysical feedbacks.
- Forests are under tremendous pressure from global change. Feedbacks in the Earth system and the potential of forests to mitigate climate change is largely unexplored



A
Area
Area (million km²)
120
100
80
60
40
20
0
Nonforest
Forest
Tropical forest
Temperate forest
Boreal forest
B
Global carbon
Carbon stock (Pg C)
2500
2000
1500
1000
500
0
Nonforest
Forest
Tropical forest
Temperate forest
Boreal forest
C
Stand carbon flux
NEP (g C m⁻² year⁻¹)
400
300
200
100
0
Humid
Evergreen
Deciduous
Semiarid
Evergreen
Deciduous
Tropical forest
Temperate forest
Boreal forest
D
Albedo
Albedo
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Snow-free
Snow-covered
Nonforest
Forest
Needleleaf evergreen
Needleleaf deciduous
Broadleaf deciduous
Mixed
E
Evapotranspiration
Normalized latent heat flux
2.00
1.50
1.00
0.50
0.00
10
100
1000
10000
Canopy resistance (s m⁻¹)
Wheat
Corn
Deciduous forest
Jack pine
Oak savanna

A. Area: forests cover about 42 million km2 (30%) of land surface
B. Global Carbon: Forests store about 45% of terrestrial carbon
C. Stand Carbon Flux: Forests can sequester large amounts of carbon annually
D. Albedo: Forests have a low surface albedo and can mask the high albedo of snow which contributes to planetary warming through increased solar heat of land
    a. Croplands have a higher albedo than forests
E. Evapotranspiration: The ratio of evapotranspiration to available energy is generally low in forest compared with some crops and lower in conifer forest than in deciduous broadleaf forest
    a. Growing season evaporative cooling is greater over watered crops compared with forests, and these plants exert less evaporative resistance

Climate Models

- Eddy covariance flux towers, free-air CO2 enrichment systems, satellite sensors, and mathematical models are used to investigate the coupling between forests and the atmosphere
- Most of the time, our understanding of how forests affect climate comes from atmospheric models and their numerical parameterizations of Earth's land surface

Climate models

- Atmospheric models require fluxes of energy, moisture, and momentum at the land surface as boundary conditions to solve numerical equations of atmospheric physics and dynamics
- Current models demonstrate biogeophysical regulation of the climate by vegetation through albedo, turbulent fluxes, and the hydrologic cycle

Tropical Forests

Current

- Climate model simulations show that tropical forests maintain high rates of evapotranspiration, decrease surface air temperature, and increase precipitation compared with pastureland
- Tropical forests contain about 25% of the carbon in the terrestrial biosphere, account for about 33% of terrestrial net primary production, and can sequester large amounts of carbon annually
- Atmospheric analyses suggest that tropical forests are carbon neutral or carbon sinks, which implies offsetting of carbon uptake by undisturbed tropical ecosystems

Future Projections

- The future of tropical forests is at risk as they are vulnerable to a warmer, drier climate, which may exacerbate global warming through a positive feedback that decreases evaporative cooling, releases CO_2, and initiates forest dieback
    - Land-use pressures are expected to continue causing a shift to a permanently drier climate

Boreal Forests

Current

- Boreal forest has the greatest biogeophysical effect of all biomes on annual mean global temperature
- Boreal ecosystems store a large amount of carbon in soil, permafrost, and wetland and contribute to the Northern Hemisphere terrestrial carbon sink

Future

- In the main boreal forest, there may be loss of evergreen trees and a shift toward deciduous trees
- Siberian forests may collapse in some areas and become more evergreen in the north
- Increased disturbance from fire or insect outbreaks will shift the forest to a younger age class
- Climate forcing arising from younger stand age may be comparable to that arising from biome shifts

Temperate Forests

Current

- Global climate models find that temperate forests in the eastern United States maintain warm summer temperature because of their lower albedo, increased by evaporative cooling from cropland feedbacks
  - mesoscale model simulations of the July climate of the United States find that trees increase evapotranspiration and decrease surface air temperature compared with crops.
- Temperate forests hold about 20% of the world's plant biomass and about 10% of terrestrial carbon
  - Carbon sequestration rates are higher in mature forests

Future

- Temperate forests in the United States historically have been carbon sources because of deforestation
  - Recent reforestation and fire suppression have shifted this towards carbon sinks but likely to decline as forests face uncertain pressures from climate change and human land use
- The net climate forcing of temperate forests is highly uncertain. The future of temperate forests and their climate services is highly uncertain. Change in the balance between deciduous and evergreen trees is likely in the future

Carbon Cycle Feedbacks

- Analyses of observed atmospheric CO2 concentrations indicate that a decline in the efficiency of the carbon cycle to store anthropogenic CO2 in ocean and land is occurring
- Climate change can enhance NPP (negative feedback) in boreal forests where temperature increases and decrease NPP (positive feedback) in tropical forests where greater evaporative demand dries soil
- Ecological responses to climate change alter the biogeophysical functioning of forests and also provide climate feedback.
  - Decreased stomatal conductance with higher atmospheric CO2 concentration reduces evapotranspiration and reinforces wearming
- More extensive tree cover may enhance warming in boreal forests by decreasing surface albedo. Reduced evapotranspiration in a drier climate may initiate a positive climate feedback leading to loss of tropical forest.

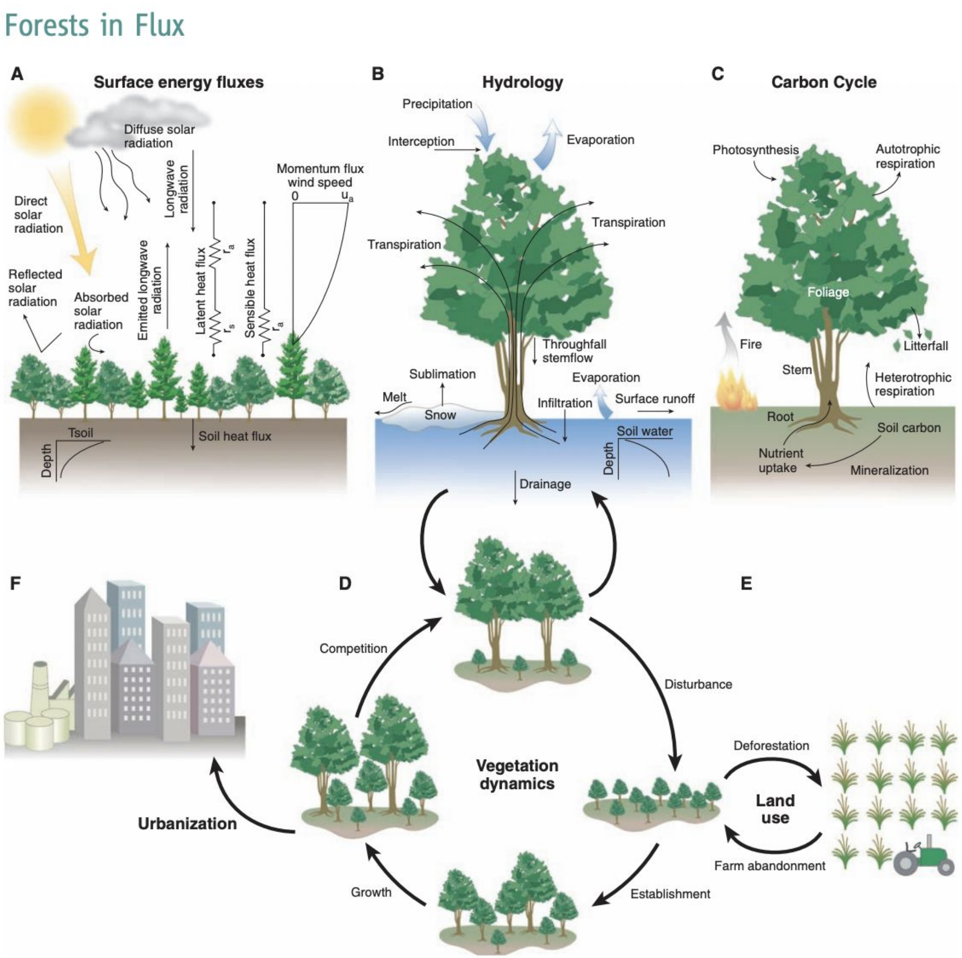


Fig 2. Biogeophysics/chemistry/geography of a terrestrial ecosystem

A. Surface Energy Fluxes: represents plant canopies, including radiative transfer, turbulent processes above and within the canopy, and the physical and biological controls of evapotranspiration
B. Hydrology: represents snow cover, soil water profile, and vegetation influences on the hydrologic cycle
C. Carbon Cycle
D. Vegetation Dynamics
E. Land use
F. Urbanization

A and B are the core of the biogeophysical processes

C and D show how plant ecosystems respond to climate change

E and F show human alteration of the biosphere

Land-Use Forcing

- Carbon emission from land use dampens biogeophysical cooling
- Biogeophysical cooling may outweigh biogeochemical warming at the global scale or may only partially offset warming. The net effect of these competing processes is small globally but is large in temperate and high northern latitudes where the cooling due to an increase in surface albedo outweighs the warming due to land-use CO2 emission
- The biogeophysical land-use forcing of climate may in some regions be of similar magnitude to greenhouse gas climate change

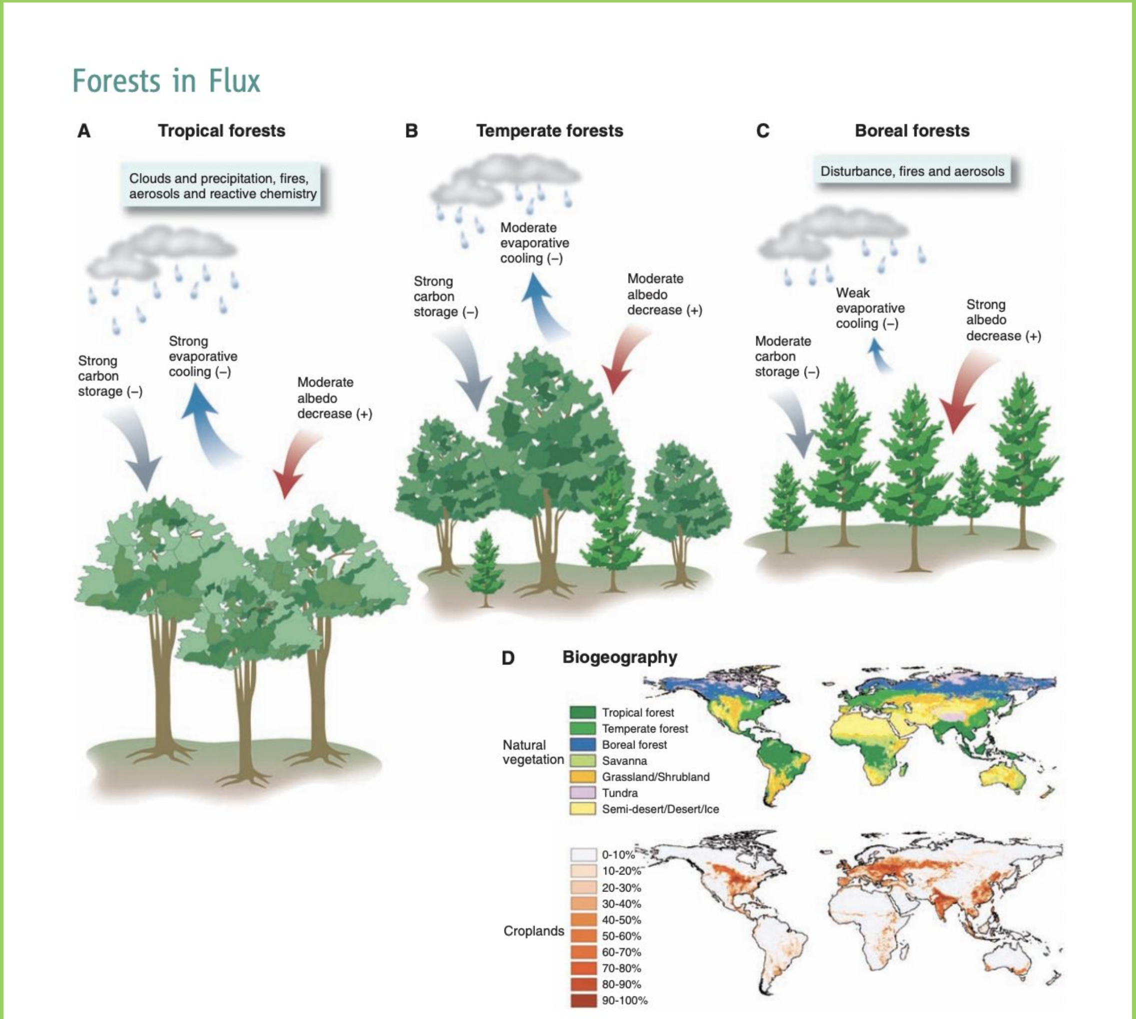


Fig 3 Climate services with key processes

A. Tropical Forest
B. Temperate Forests
C. Boreal Forests
D. Natural vegetation biogeography in the absence of human uses of land vs croplands during 1990s
    a. Shows much of the natural vegetation of the world has been cleared for

Results

- Forests and human uses of forests provide important climate forcings and feedbacks, that climate change may adversely affect ecosystem functions, and that forests can be managed to mitigate climate change
- Tropical afforestation is likely to “slow down” global warming, whereas temperate afforestation has “little to no” climate benefit and boreal afforestation is “counterproductive”

Research Needs

- What is lacking is science that integrates the many interacting climate services of forests with the impacts of global change to inform climate change mitigation policy
- The climate forcing of boreal forests is less certain along with the climate benefit of temperate forests
- More realistic depictions of vegetation dynamics
    - Time scales of vegetation response to disturbance
    - Fires, aerosols, and reactive chemistry

QUESTIONS?