Ch. 2.1.3 Role of biosphere in climate

- Text, Ch. 2.1.3, 2.1.4: biosphere
- Reading assignment: Sagan & Mullen 1972
  Watson and Lovelock 1983

Questions:
1. How importance is the biosphere to climate?
2. How does biosphere influence the physical properties of the climate system?
Gaia Hypothesis:

- James Lovelock and Lynn Margulis, 1970s: Life (organisms) interacts with their inorganic surroundings on Earth to form a self-regulating, complex system that contribute to maintaining the conditions for life on the planet, including maintain stability of the earth’s climate.
2.1.3 The terrestrial Biosphere:

- Much of climate impact upon human and animals is through its regulation on terrestrial biosphere, e.g., forests, grass, tundra, etc.

- Biosphere can influence climate through
  1. Water cycle: ET
  2. Energy balance: ET, albedo
  3. Biochemistry: carbon cycle, aerosols (biogenetic, dust)
Dependence of biomes on climate:

- Annual-mean temperature
- Annual and diurnal ranges of temperature
- Annual mean and seasonal distribution of rainfall and cloudiness

Conceptual framework for preferred vegetation types for various climate regimes as determined by surface temperature and precipitation.
Role of terrestrial vegetation in determining atmospheric water and carbon fluxes and climate.

ABL aerodynamic properties and surface soil moisture determine the surface fluxes.

Rn-G, H, IH, Pnet
Influence of vegetation on surface water balance:

- Vegetation can draw moisture from subsurface soil layer through transpiration, different vegetation type provides different ET for similar meteorological conditions.
- Intercept precipitation and re-evaporate intercepted water and reduce runoff and soil erosion,
- Uptake atmospheric carbon through photosynthesis;
- Change surface albedo
- Detergent for the atmosphere

von Randow et al. 2004
Ecosystem and global carbon cycle

Net abs over land~2.6

3.3 emission stays in atmosphere

Net abs over ocean~2.2

Black: natural and unperturbed exchange

Red: perturbed and anthropogenic flux

(IPCC, AR4)
Response of terrestrial biosphere to climate:

• Increase of biomass leads to CO$_2$ sequestration in boreal high latitudes:

• Reduce high latitude albedo, increasing solar absorption at the surface.
Northern High-Latitude Ecosystems Respond to Climate Change

Importance of terrestrial vegetation to global climate:

Future:

- Recent Coupled Carbon-Climate Models Inter-comparison Project suggest that the response of terrestrial biosphere to $2\times$CO$_2$ cause additional increase of global atmospheric CO2 by 50-150 ppm, leading to additional 0.5-1.5°C increase in global surface temperature (Friedlingstein et al. 2006);
- However, this estimate does not consider the effect of vegetation albedo change on climate.
• Terrestrial biosphere feedback loops:

**Carbon feedbacks**

**physical feedbacks**

**Figure 1**
Schematic diagram of major processes involved in the control of CO₂ feedbacks (panel a) and physical feedbacks (panel b) in the climate system. A plus (+) symbol indicates that an increase in one process leads to an increase in the next, and a minus (−) symbol indicates that an increase in one process leads to a decrease in the next. Note that the set of driving processes (plant growth, biome shifts, and disturbance) is mostly the same for the CO₂ and physical feedbacks.

Field et al. 2007
Albedo vs. carbon cycle:
Response of boreal ecosystem to increase of CO2:
The warming due to darkening of surface albedo can compensate cooling due to CO₂ sequestration (Betts 2000 Nature)
• Controlling processes:
  – CO2: photosynthesis, respiration by plants, animals, microbes, combustion;
  – Impacts of climate and land use
    • Stimulating photosynthesis by high CO2 or improve growing condition (warming, longer or earlier growing season, improve moisture and nutrient availability)
    • Change respiration by alter physical, chemical conditions and soil organic matters
    • Replacing low biomass plants by high biomass plants or vice versa
    • disturbances from natural to anthropogenic processes, e.g., species changes and conversion from forest to crops, from desert to crops.
    • Increase drought in subtropics and tropics reduce carbon in biosphere and soil.
Changes of ecosystem feedbacks with latitude:

Field et al. 2007

Figure 3
Estimated quantitative range for net climate forcings from a range of ecosystem feedbacks at high and low latitudes. Black horizontal bars represent most likely outcomes, based on our conceptual model. Gray dashed lines represent most likely outcomes if wildfire increases dramatically. Note that the net effect of all of the poorly modeled processes is likely to be positive net forcing, but also note that all of the ecosystem forcings are small in relation to the net forcing from fossil emissions. Abbreviations: GHG, greenhouse gas; C4MIP, Coupled Climate-Carbon Cycle Model Intercomparison Project.
The human factor: Worldwide extent of human land-use and land-cover change

(Foley et al. 2005. Science 309)
Facts about human impact on terrestrial biosphere:

- ~50% of the potentially vegetated land surface has been affected by agriculture (Foley et al. 2005);

- Global crop land area increased from 4 million km$^2$ in 1700 to ~18 million km$^2$ in 1990s, with 2 million km$^2$ were abandoned in the same period (Ramankutty and Foley 1999);
Carbon Cycle (years-centuries) :
Currently only about half of human emissions of CO2 remain in the atmosphere - the ocean and land ecosystems are absorbing the remainder.
The human factor: CO$_2$ emissions from land use change
Role of Agriculture in global terrestrial carbon and water balance.
Impact of agriculture on global water cycle:

• Reduce transpiration by 5%, interception by 20%,
• increase evaporation by ~44%,
• not affecting runoff globally.

Fig. 16 Global agriculture-related water trends in the 20th century: (a) transpiration \(10^3 \text{ km}^3\), Lund–Potsdam–Jena (LPJ) and LPJ managed Land (LPJmL); (b) interception \(10^3 \text{ km}^3\), LPJ and LPJmL; (c) evaporation \(10^3 \text{ km}^3\), LPJ and LPJmL; (d) runoff \(10^3 \text{ km}^3\), LPJ and LPJmL.
Impact on global carbon budget as a function of time (1990-2000):

- Natural vegetation increased due to CO2 fertilization;
- As fraction of crop area increased by 50%, harvest of carbon doubles;
- Vegetation carbon decreases due to increase of crop; The global vegetation+crop change to a weak sink since 1970 due to slower rate of increase crop land and CO2 fertilization.

Grazing: 3.6 PgC yr\(^{-1}\)
Crop: 2.2 PgC yr\(^{-1}\)
• How to manage residue of the crop is important for carbon budget;
• Increase crop productivity closes the gap in NPP between natural and natural+agr land;
• Natural vegetation was carbon neutral, but agriculture+natural acts as a carbon source until 1970s.

Residue management

Due to increase irrigation
And productivity

![Graphs showing residue management](image)
Question:

• If we examine the carbon feedbacks to climate using a purely natural vegetation model, will this model provide an acceptable answer? Do you expect this model to under or overestimate the carbon increase in the atmosphere?
Summary:

• Biosphere plays a central role in regulating global carbon cycle. It dominates the climate-carbon feedbacks, is a main source of uncertainty in climate projection for the next century.

• Terrestrial biosphere provides both physical (albedo, water) and biochemical feedbacks (carbon, CH4, O3). These feedbacks may work for or against each other.

• Human impact, such as land use impact on terrestrial biosphere has significantly changed global water (20-40%) and carbon cycles (30% of global anthropogenic carbon emission), and compromise the natural ecosystem’s ability to regulating earth’s environment and climate.
2.1.4 The earth’s crust and mantle

- Influence climate on hundred-million year time scales
- Determine the continent-ocean configuration;
- Control chemical weathering of rocks (draw down CO2 from the atmosphere) and volcanic activity, which in turn, release carbon and aerosols into the atmosphere.