Carbon-Water Coupling

Inez Fung
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Atmosphere

\[ \text{CO}_2 = 280 \text{ ppmv (560 PgC)} + \ldots \]

Ocean Circ. + BGC

37400 Pg C

90±

Turnover Time of C

10^2-10^3 \text{ yr}

Biophysics + BGC

2000 Pg C

60±

Turnover time of C

10^1 \text{ yr}

• Specify FF emissions
  • 19th-20th century – historical emissions
  • 21st century – SRES A2 and A1B
• Model Expts:
  • Coupled: radiatively active CO2 = prognostic
  • Uncoupled: radiatively active CO2 = 282 ppmv (control climate)
All models: with C-climate feedback $\rightarrow$ higher CO$_2$, warmer

Friedlingstein et al. (J Clim, 2006)
C4MIP Robust Result: Reduce ocean & land carbon storage capacities

Carbon-climate feedback accelerates warming
C-CSM1.4: 21st C Correlations & Regressions

$\text{FF} = \text{SRES A2}; \, \delta = \text{Coupled minus Uncoupled}$

$\{\delta T, \delta \text{Soil Moisture Index}\}$

Regression of $\delta \text{NPP} \text{ vs } \delta T$

NPP decreases with carbon-climate coupling

Fung et al. Evolution of carbon sinks in a changing climate. PNAS 2005
### Large Variations NPP and Respiration Sensitivities to Temperature

Table 7.5. Effective sensitivities of land processes in the CMIP models: percent change of vegetation NPP to a doubling of atmospheric CO₂ concentration (Column 2), and sensitivities of vegetation NPP and specific heterotrophic soil respiration to a 1°C global temperature increase (Columns 3 and 4).

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Global NPP sensitivity: depends on cancellation bet’ warm-wet regions and warm-dry regions
Soil Moisture

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IPCC AR4 Ch7
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Jung-Eun Lee: Hydraulic Redistribution by Roots
Charlie Koven: Dust Bowl

Inez Fung
UC Berkeley
Leaf Photosynthesis

Piers Seller’s PAR Diagram
ET ~65% of rainfall
Transp ~ 50% ET
Carbon Assimilation Rates of Sun and Shade Leaves
(Sellers et al. J Climate 1996; Bonan et al. - LSM)

Per area of leaf sfc:
\[ A_{sun,shade} = \min \{ \]
\[ \text{PEP-Carboxylase, Light}_{sun,shade}, \]
\[ \text{Export/utilization} \} \]
limited rates of assimilation

Normalize canopy
\[ \text{GPP} = \]
\[ A_{sun} \times f_{sun} \times \text{LAI} \]
\[ + A_{shade} \times f_{shade} \times \text{LAI} \]
Vertical Root Distribution constrained by observation

Fraction of deep root is obs very small

Model: Access mainly soil moisture near surface

Data from Jackson et al. (1996)

Fig. 1 Cumulative root distribution (cumulative proportion) as a function of soil depth for eleven terrestrial biomes and for the theoretical model of Gale and Grigal (1987). The curve in each biome panel is the least squares fit of $\beta$ for all studies with data to at least 1 m depth in the soil. The specific $\beta$ values and the associated $r^2$ values can be found in Table 1 and the key to the symbols in each panel is in Table 2. Gale and Grigal’s equation is of the form $Y = 1 - \beta^d$, where $Y$ is the cumulative root fraction with depth (a proportion between 0 and 1), $d$ is soil depth (in cm), and $\beta$ is the fitted parameter. Larger values of $\beta$ imply deeper rooting profiles.
Deep Roots have larger channels

Deep roots have water transport conduits with much greater diameters à higher hydraulic conductivity (5~20 times)

Picture from Jackson et al., 2000
Observation From the Amazon

R. Oliveira

Oliveira et al., 2006
Isotope of vegetation reflect water source

Willows have deep roots

Grasses have shallow roots

Welker 2000
Hydraulic Redistribution in CAM2:

increases photosynthesis and transpiration during the dry season

Lee et al. PNAS 2005
Seasonality of Soil Moisture

With Hydraulic Redistribution

Without Hydraulic Redistribution

Banking water

More deep soil moisture seasonality in the run with hydraulic redistribution. Banking of water in deep soils to survive droughts.
Impact of hydraulic redistribution in CAM2

$\Delta$ 2m Temperature

$\Delta$ET:
- Amazon: extends into dry season
- Elsewhere: largest impact in water stressed regions

Lee et al. PNAS 2006
Carbon-Water Coupling

Jung-Eun Lee: Hydraulic Redistribution by Roots
Charlie Koven: Dust Bowl
Case Study: 1930’s dust bowl in US

1930s Great Plains Precipitation Anomalies from Global Historical Climatology Project

Dust storm frequency, March 1936, from Martin (1936)

Number of days with duststorms, or dusty conditions, March 1936.—W. A. M
Specify 3D dust distrib from MATCH-DEAD for CAM2 expts

(a) Map of mean dust aot for apr-may
(b) Timeseries of dust aot over dust-bowl region
(c) Profile of dust mass mixing ratio over dustbowl area for months apr-may
Dust Radiative Forcing

- No dust
- SSA=0.90
- SSA=0.95
- SSA=0.975

Atm. absorp.

Surface Forcing

Top of Atm. Forcing
Dust Radiative Forcing

Atm. absorp.

Surface Forcing

Top of Atm. Forcing

No dust  SSA=0.90  SSA=0.95  SSA=0.975
Precip Anomalies, April-May

SSTA

Dust+SSTA

VegA

Dust+VegA+SSTA

Dust+VegA+SSTA – VegA
The Regional Hydrologic Cycle

\[
\frac{\partial q}{\partial t} = \nabla \cdot (v q) + \text{Evap} + \text{Transp'} n - \text{Condens'} n
\]

- remote
- local land surface
- local atmosphere

q = water vapor mixing ratio, kg H2O/kg air
Potential Dust Sources based on slope and roughness

Feedback:
- drying/ deforestation/ urbanization
  - reduce ET
  - further drying
  - more dust
  - further drying …
Carbon-Water Coupling

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Outlook
Urbanization or deforestation
- decrease terrestrial carbon storage
  - increase airborne CO2 fraction
  - accelerate climate change
- reduce evapo-transpiration
  - Increase sensible heating
  - Reduce residence time of soil moisture
  - Increase runoff where precipitation >= present day
- increase dust burden in atm
  - Decrease energy for evaporation
  - Increase stability of atm column: reduce convection
  - Increase iron deposition to the ocean
  - Increase marine productivity
  - Decrease airborne CO2 fraction
1. How are short- and long-wave radiative transfer to be incorporated in reasonably simple models?
2. How does one deal numerically with convective heat transfer?
3. How does one take into account evaporation and condensation of water substance?
4. Since the amount of solar energy absorbed by the earth-atm system depends on the albedo, one must be able to predict the cloud distribution. How shall this be done?
5. What is the mean climatological distribution of the various energy sources and sinks in the atmosphere?
6. How does the wind-driven and thermohaline ocean circulation react back on the atmosphere to produce climate change?
7. ... what is the order of the above-named energy sources in the dynamics of the general circulation? What is a minimal set of energy sources and sinks for the prediction of the gross climate?
8. How is energy dispersed from one system to another so as to bring about the observed high instantaneous correlation in type from one planetary wave to another?
9. how does one determine climatological statistics? Can we replace time averages by ensemble averages, and if so, how does one choose the ensemble?
10. what kinds of initial state does one select if the time average method is to be used, or how does one select the members of the ensemble so that they lie in mutually accessible regions of the phase space?
I hope you will not find this list of questions discouraging. I do not feel discouraged. But I think that you will all agree that progress toward the solution of these problems calls for a concerted effort on the part of all of us.