Carbon-Water Coupling

Inez Fung

UC Berkeley

Biogeochemistry Working Group

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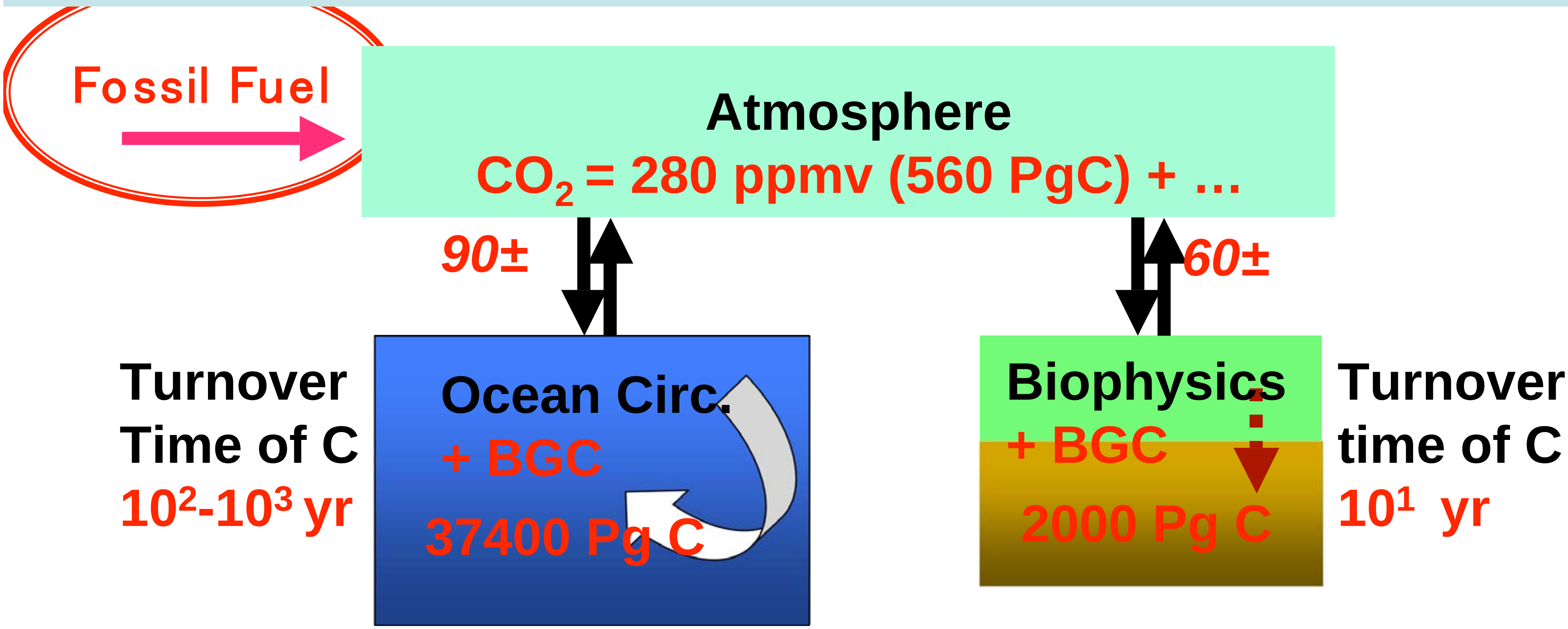
Thanks to
NSF
DOE

Coupled Carbon-Climate Experiments



Fossil Fuel

Atmosphere

CO_2 = 280 ppmv (560 PgC) + …

90±

60±

Turnover Time of C

10^2-10^3 yr

Ocean Circ.

+ BGC

37400 Pg C

Biophysics

+ BGC

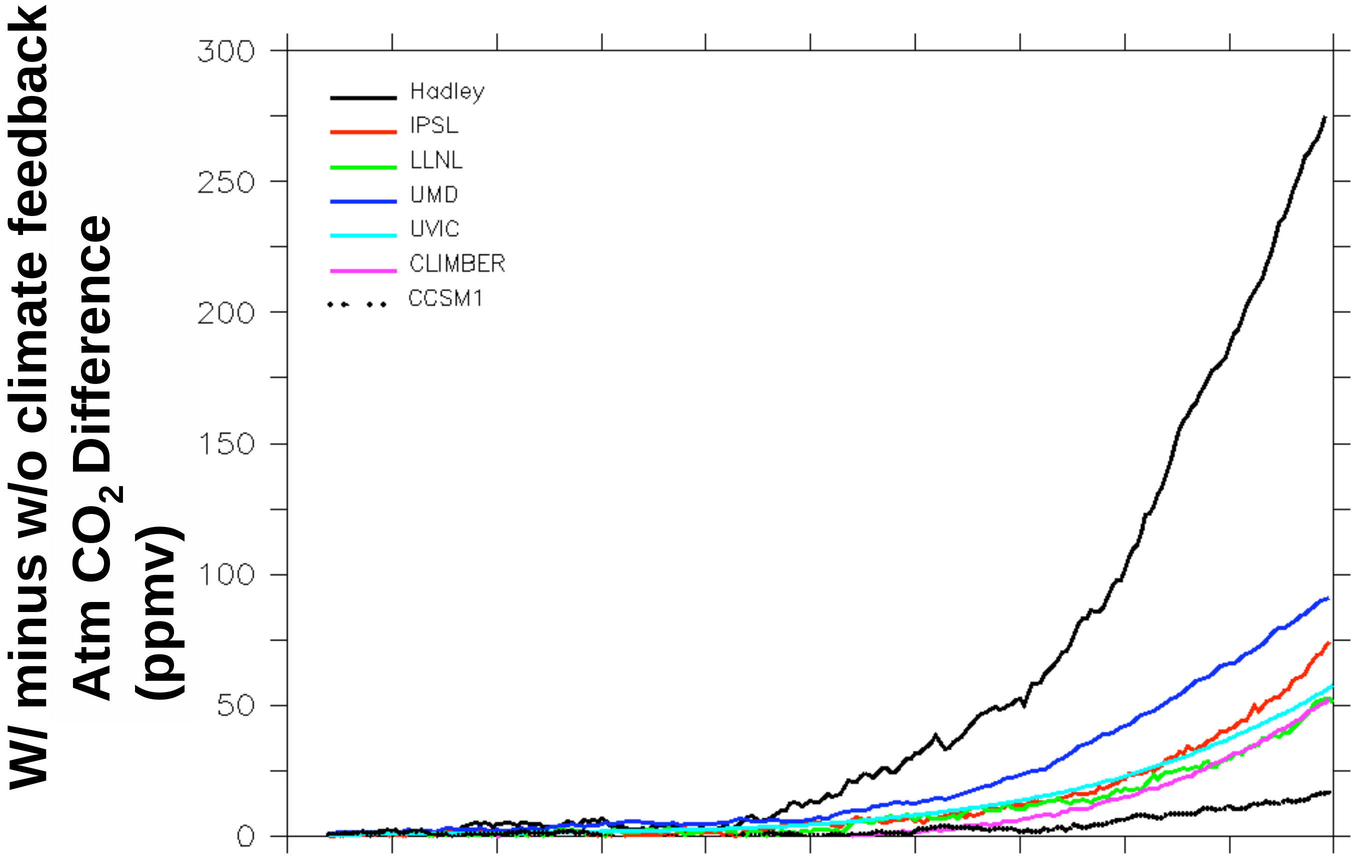
2000 Pg C

Turnover time of C

10^1 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)**

WCRP-IGBP Coupled Carbon Cycle Climate (C4MIP): FF=historical + SRES A2, BYOM



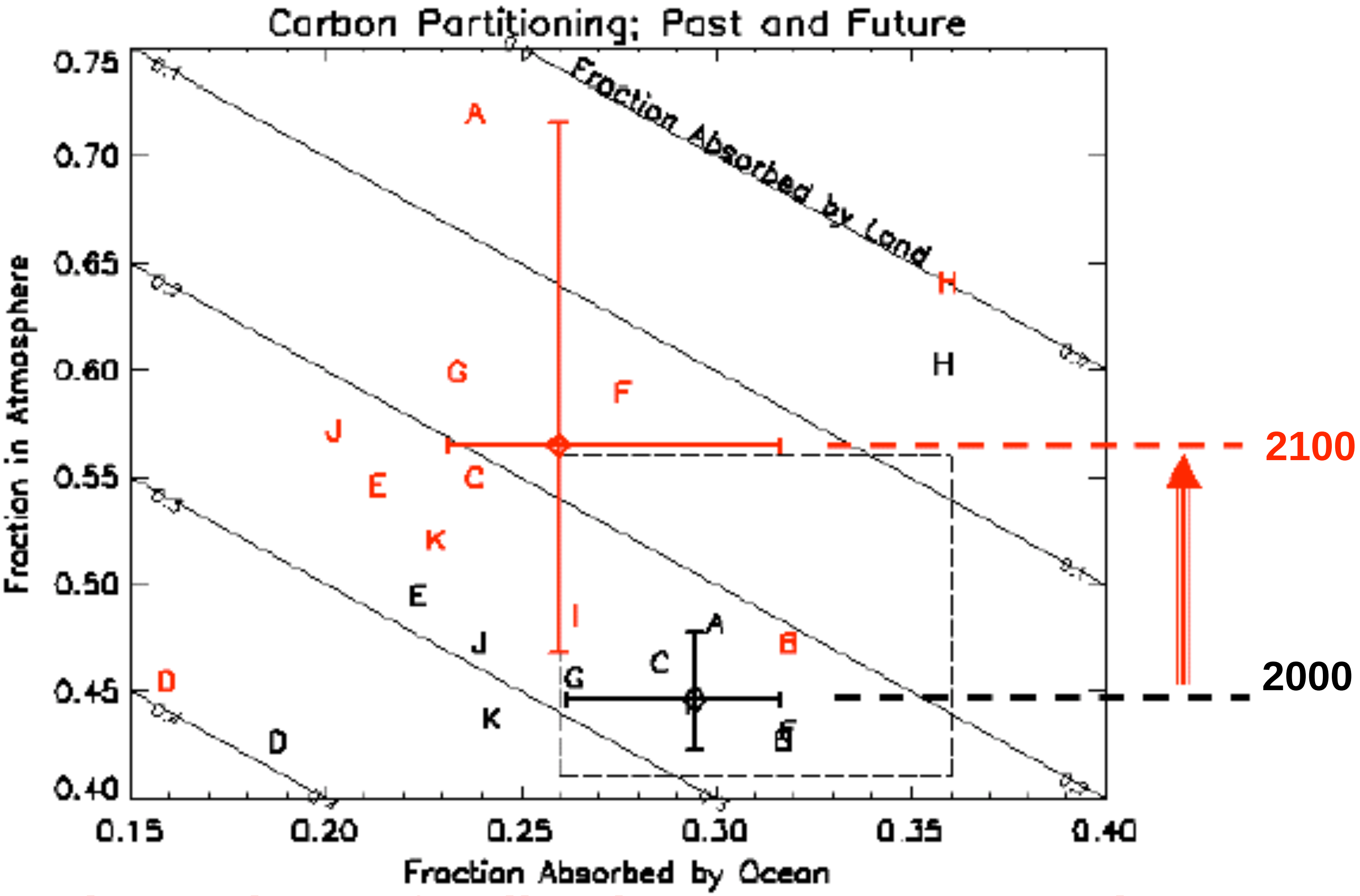
Cox et al (2000)

Fung et al. (2005)

All models: with C-climate feedback → higher CO$_2$, warmer

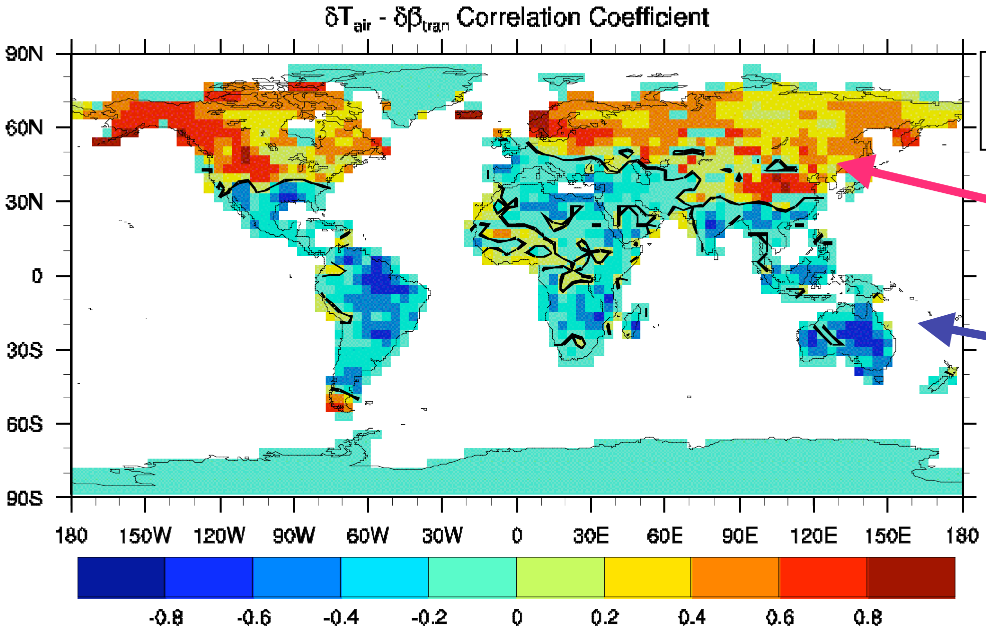
Friedlingstein et al. (J Clim, 2006)

C4MIP Robust Result:
Reduce ocean & land carbon storage capacities



Carbon-climate feedback accelerates warming

C-CSM1.4: 21st C Correlations & Regressions
FF= SRES A2 ; δ = Coupled minus Uncoupled

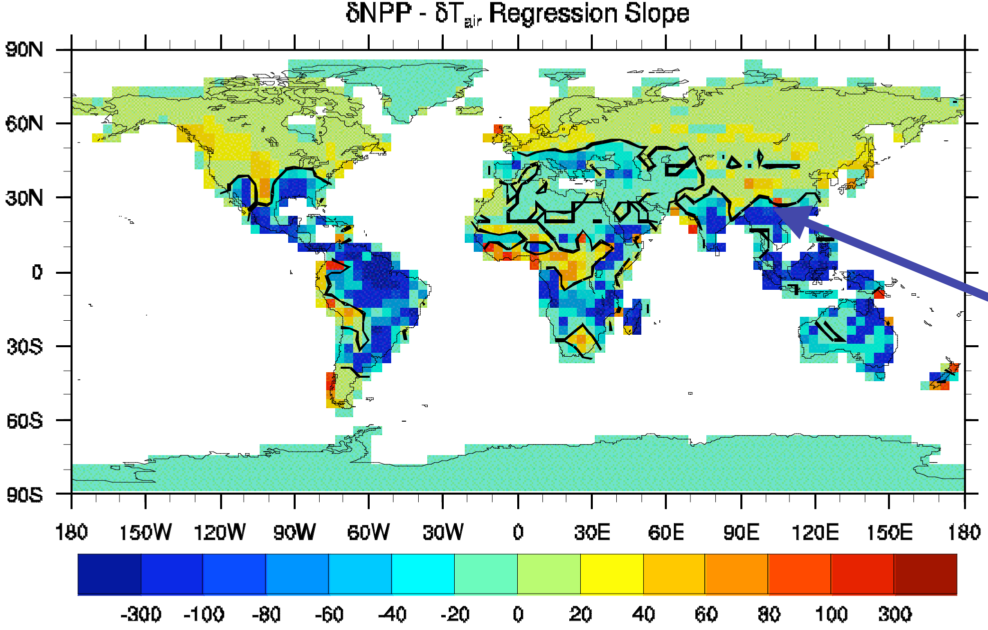


δT_{air} - $\delta\beta_{tran}$ Correlation Coefficient

{δT, δSoil Moisture Index}

Warm-wet

Warm-dry



δNPP - δT_{air} Regression Slope

Regression of δNPP vs δT

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

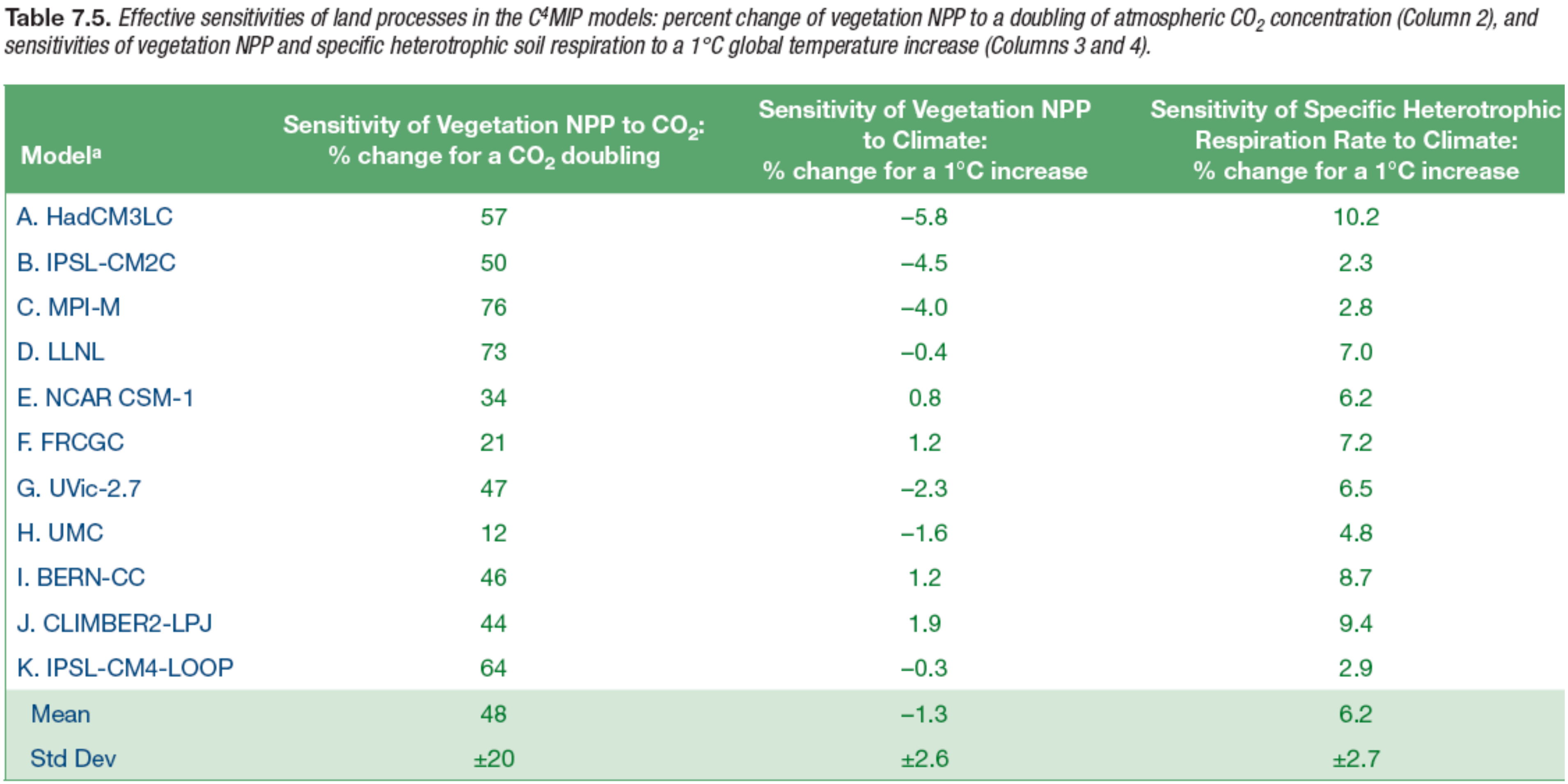


Table 7.5. *Effective sensitivities of land processes in the C⁴MIP models: percent change of vegetation NPP to a doubling of atmospheric CO_2 concentration (Column 2), and sensitivities of vegetation NPP and specific heterotrophic soil respiration to a 1°C global temperature increase (Columns 3 and 4).*

Model[a]	Sensitivity of Vegetation NPP to CO_2: % change for a CO_2 doubling	Sensitivity of Vegetation NPP to Climate: % change for a 1°C increase	Sensitivity of Specific Heterotrophic Respiration Rate to Climate: % change for a 1°C increase
A. HadCM3LC	57	–5.8	10.2
B. IPSL-CM2C	50	–4.5	2.3
C. MPI-M	76	–4.0	2.8
D. LLNL	73	–0.4	7.0
E. NCAR CSM-1	34	0.8	6.2
F. FRCGC	21	1.2	7.2
G. UVic-2.7	47	–2.3	6.5
H. UMC	12	–1.6	4.8
I. BERN-CC	46	1.2	8.7
J. CLIMBER2-LPJ	44	1.9	9.4
K. IPSL-CM4-LOOP	64	–0.3	2.9
Mean	48	–1.3	6.2
Std Dev	±20	±2.6	±2.7

IPCC AR4 Ch7

Global NPP sensitivity: depends on cancellation bet' warm-wet regions and warm-dry regions

Soil Moisture

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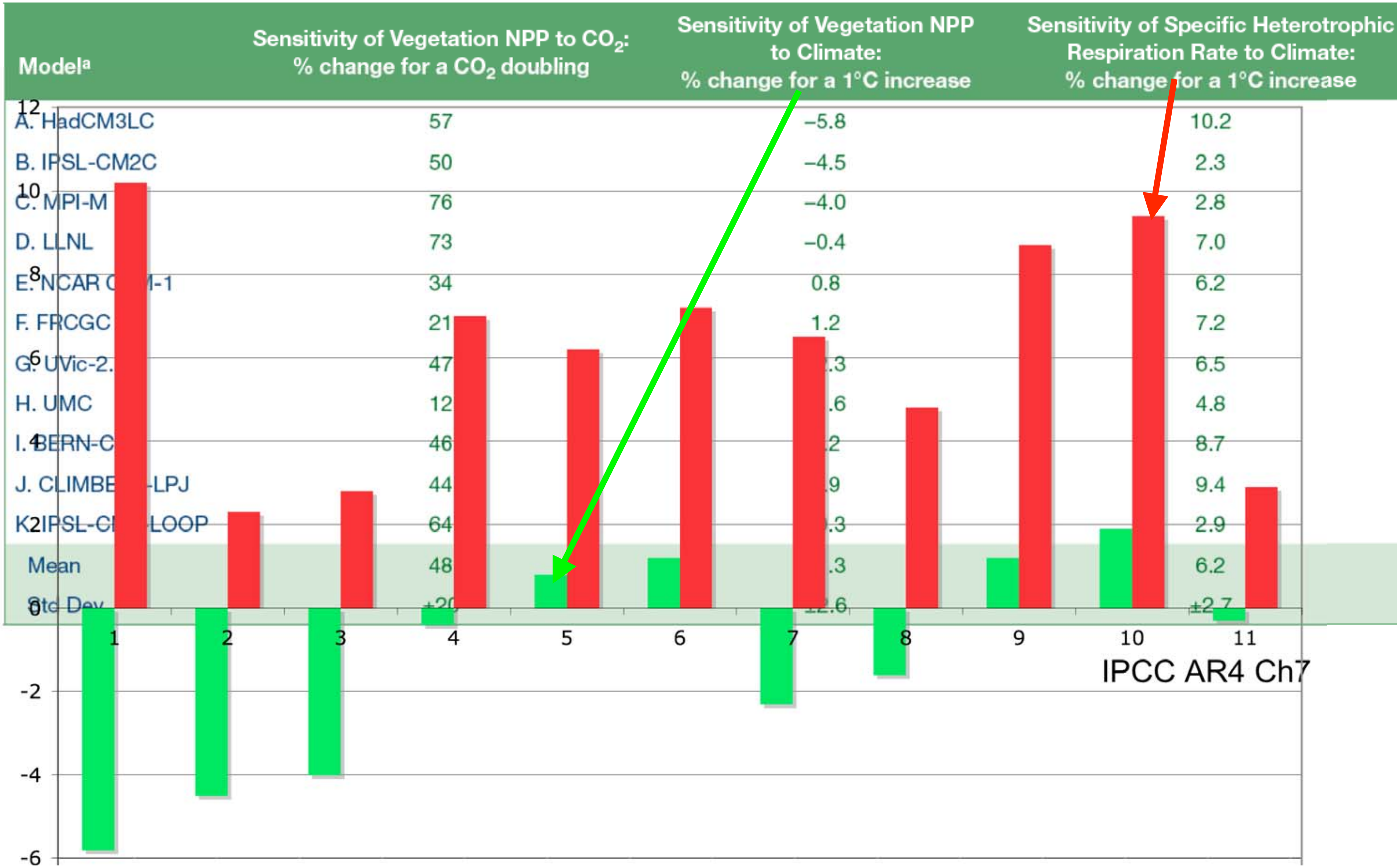

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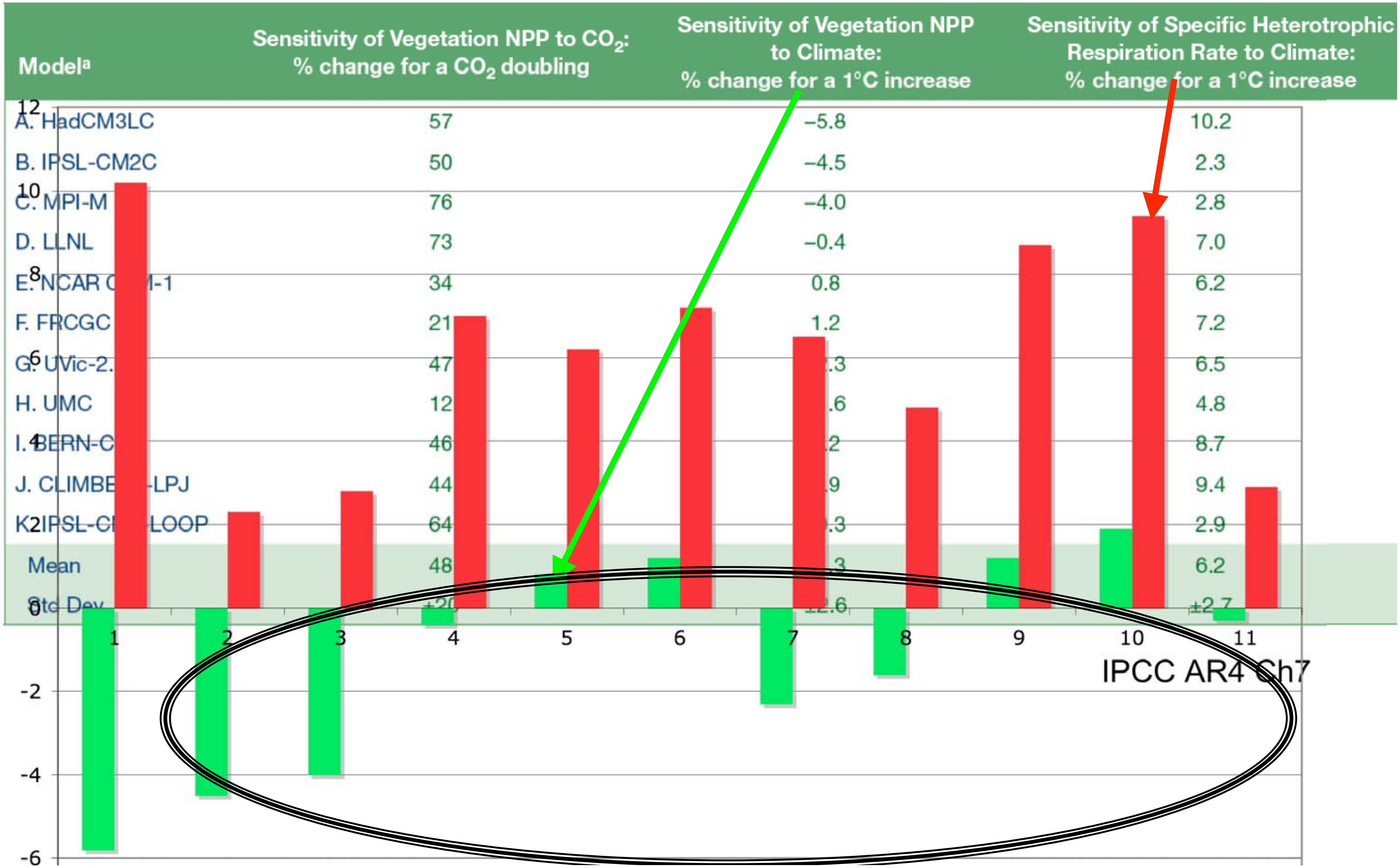

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IPCC AR4 Ch7

Carbon-Water Coupling

Jung-Eun Lee: Hydraulic Redistribution by Roots

Charlie Koven: Dust Bowl

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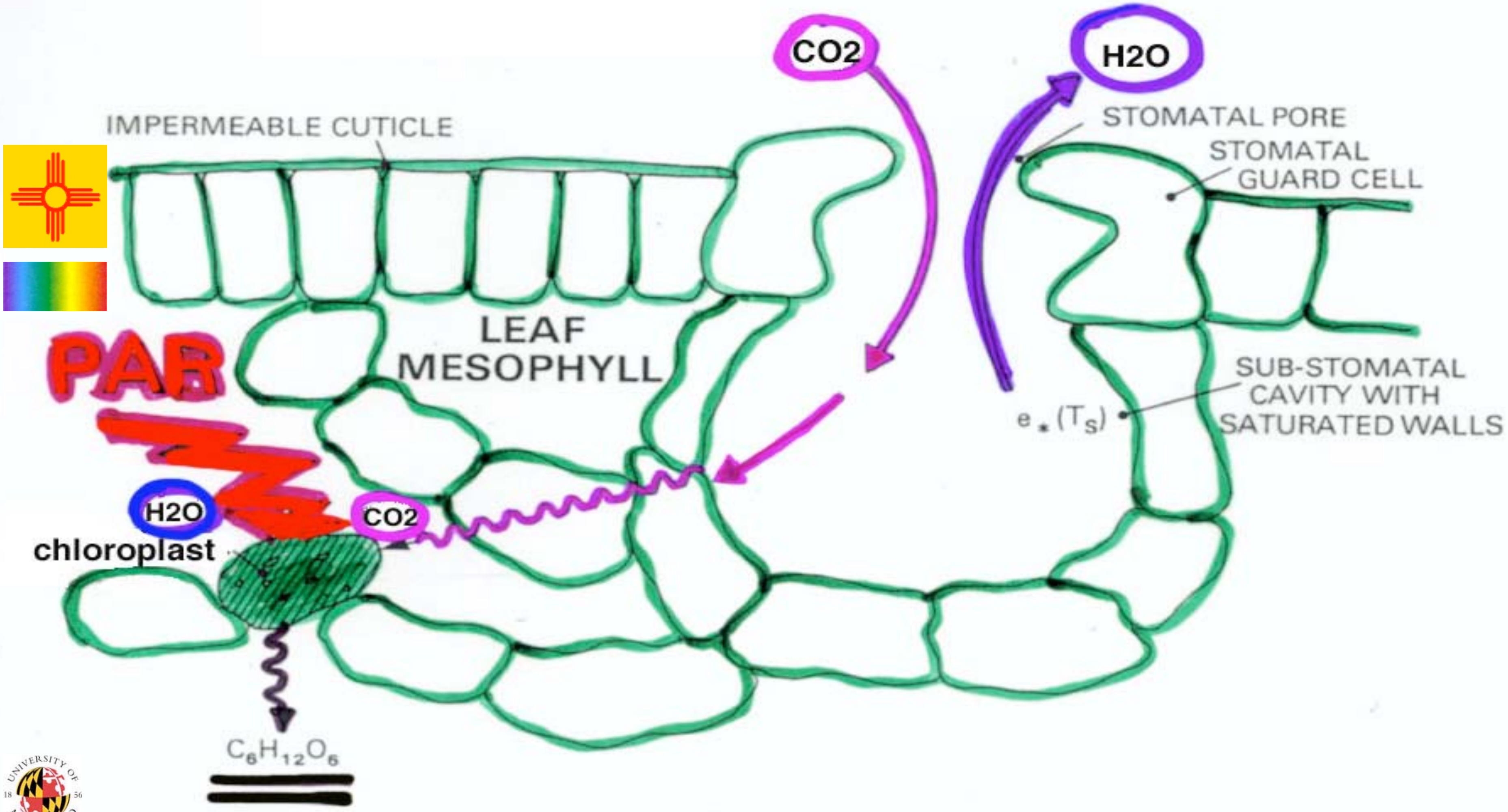
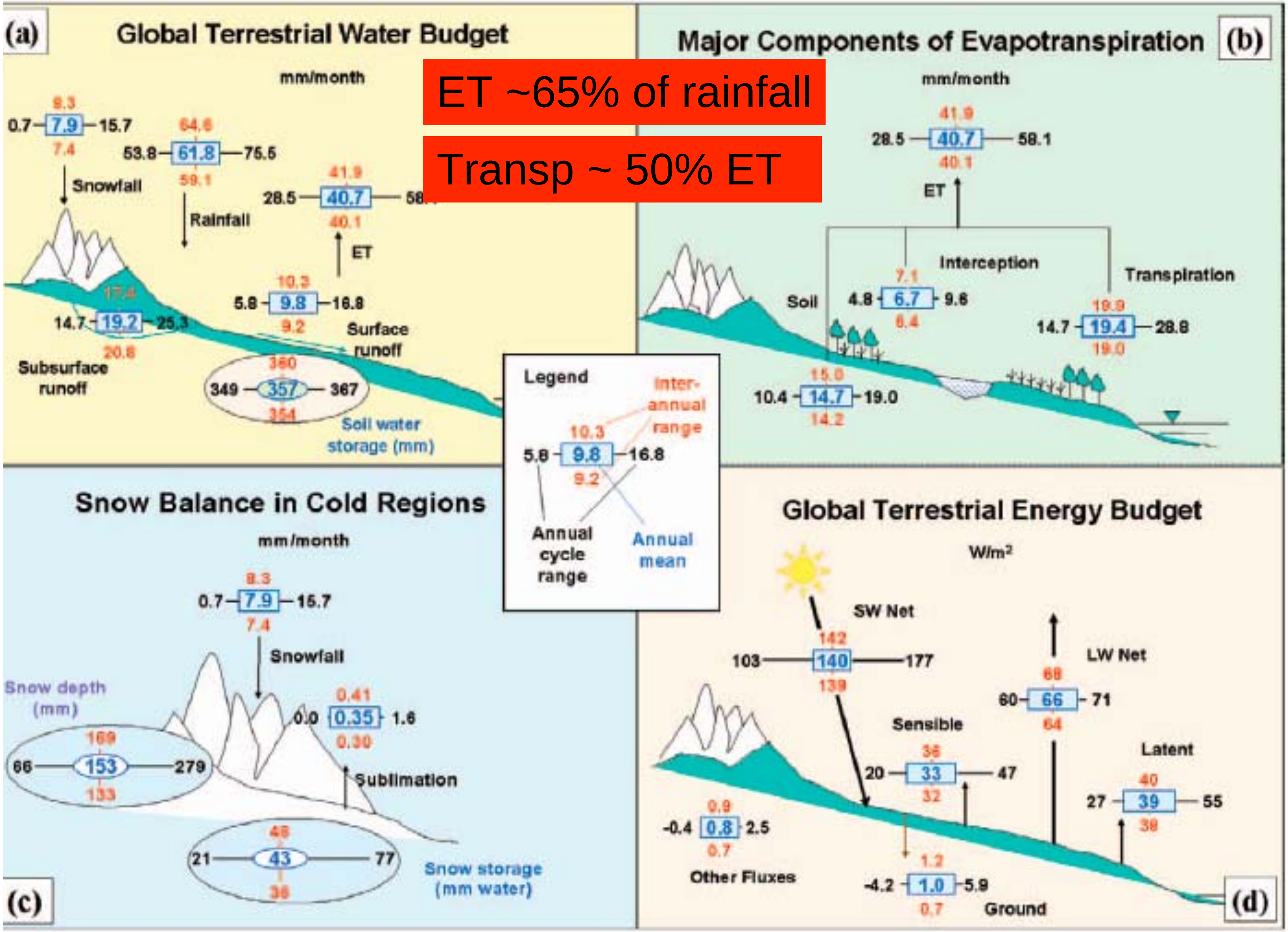
Leaf Photosynthesis
Piers Seller's PAR Diagram



ET ~65% of rainfall

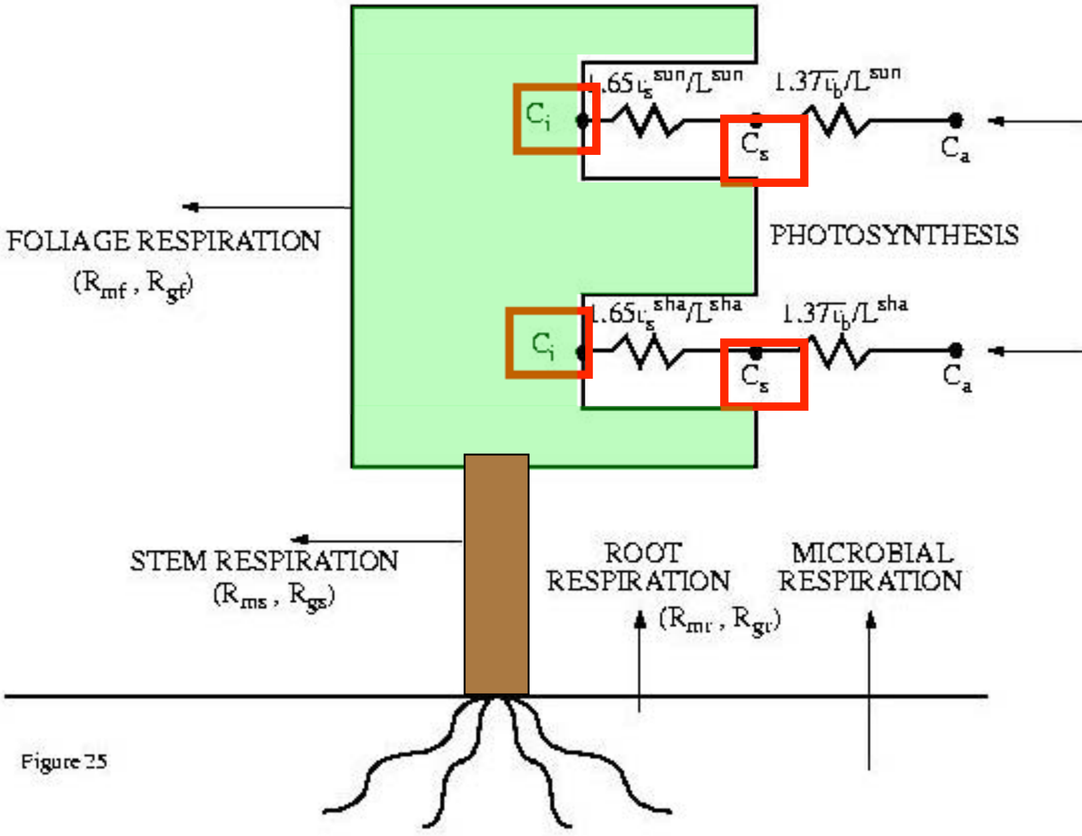
Transp ~ 50% ET



…e 4 Components of (a) the surface hydrologic balance (b) total evapotranspiration (c) the surface snow

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 {

PEP-Carboxylase ,

Light_*sun,shade* ,

Export/utilization }

limited rates of assimilation

Normalize canopy

GPP =

A_*sun* * f_sun*LAI

\+ A_*shade* * f_*shade* * LAI

Vertical Root Distribution constrained by observation

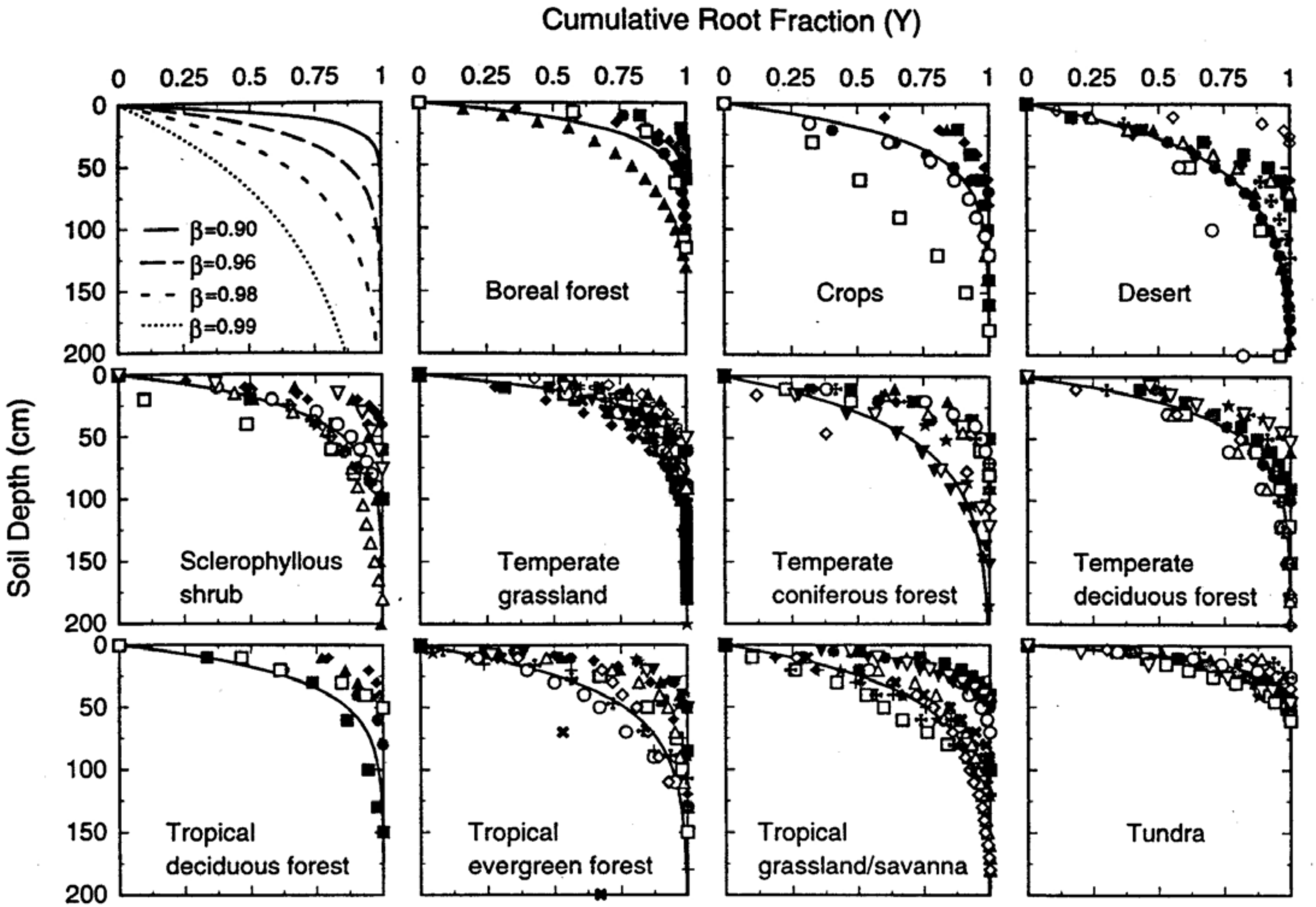


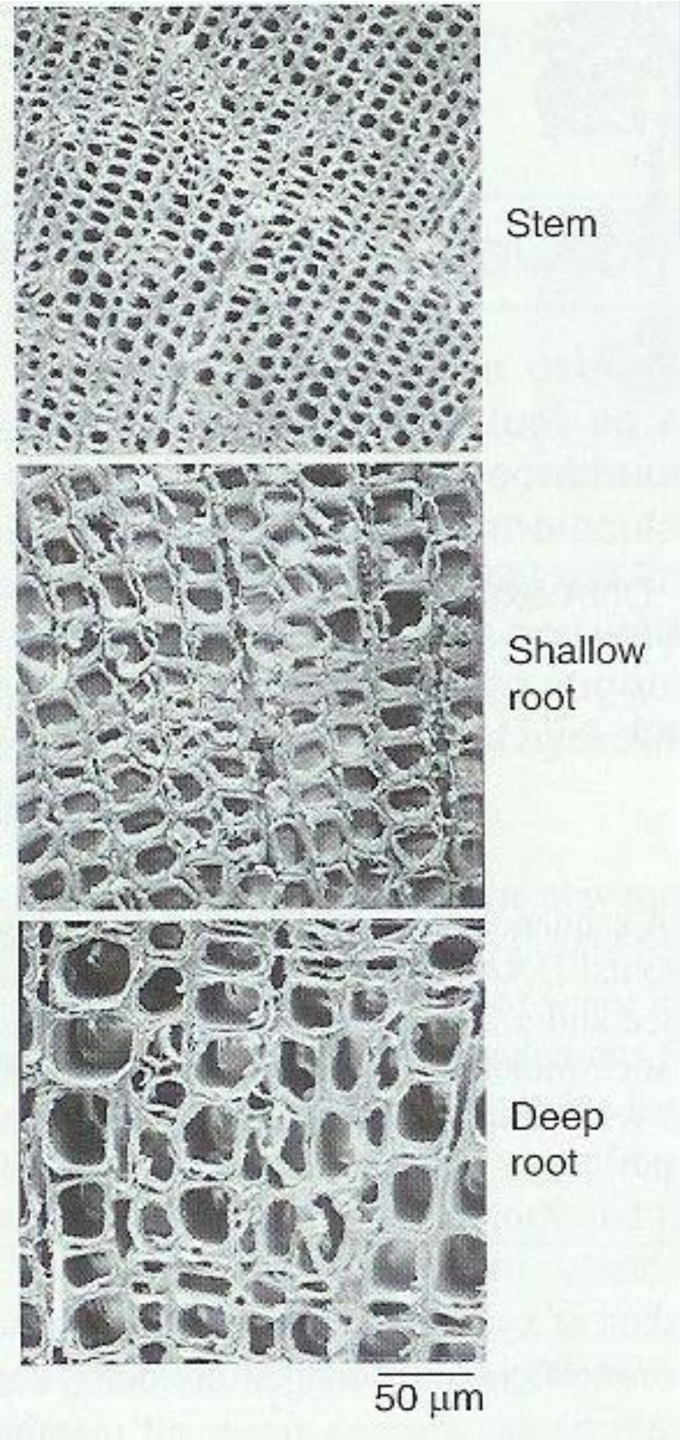
Fig. 1 Cumulative root distribution (cumulative proportion) as a function of soil depth for eleven terrestrial biomes and for the theoretical model of Gale and Grigal (1987). The curve in each biome panel is the least squares fit of β for all studies with data to at least 1 m depth in the soil. The specific β 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 β is the fitted parameter. Larger values of β imply deeper rooting profiles

Fraction of deep root is obs very small

Model: Access mainly soil moisture near surface

Data from Jackson *et al.* (1996)

Deep Roots have larger channels

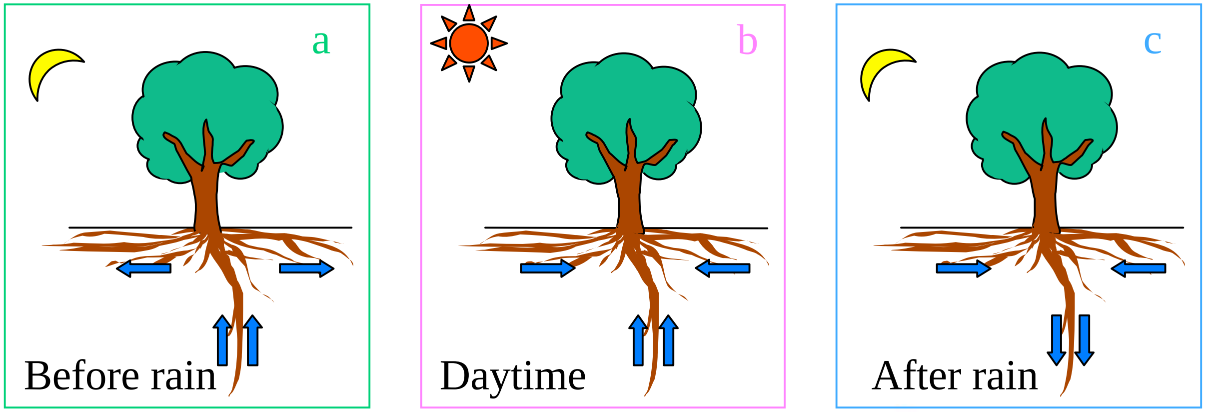


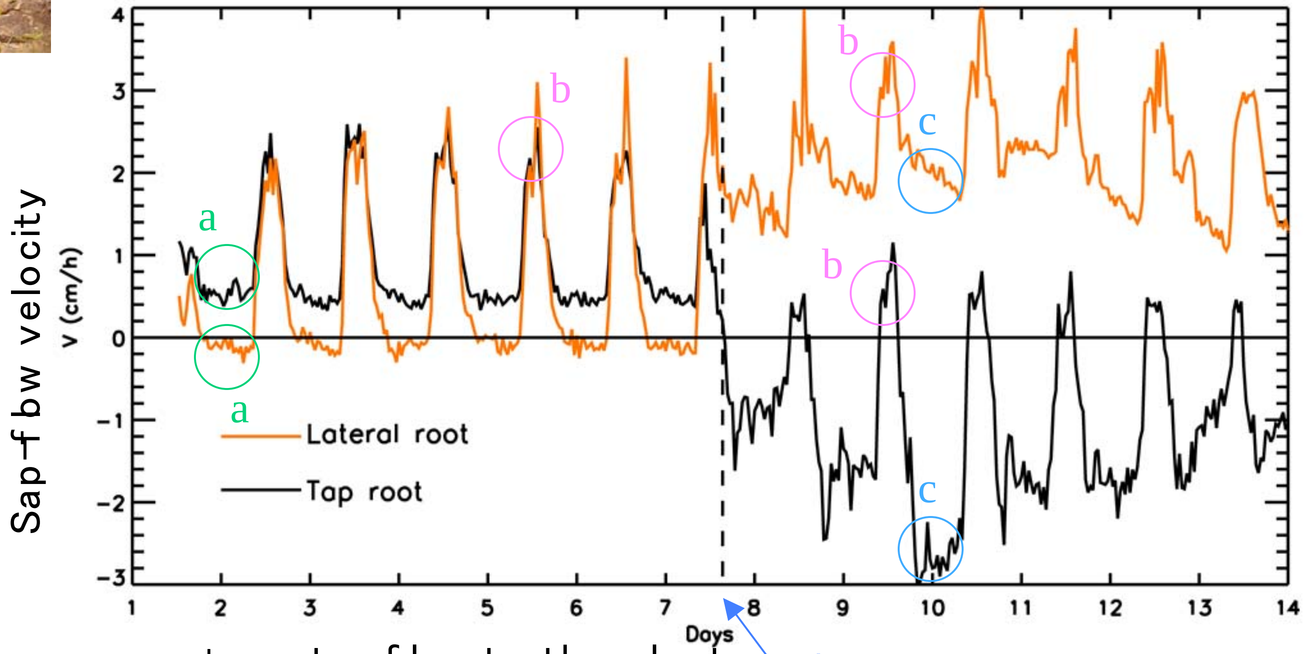
Deep roots have water transport conduits with much greater diameters à higher hydraulic conductivity (5~20 times)

Picture from Jackson *et al.*, 2000

Observation From the Amazon

R. Oliveira



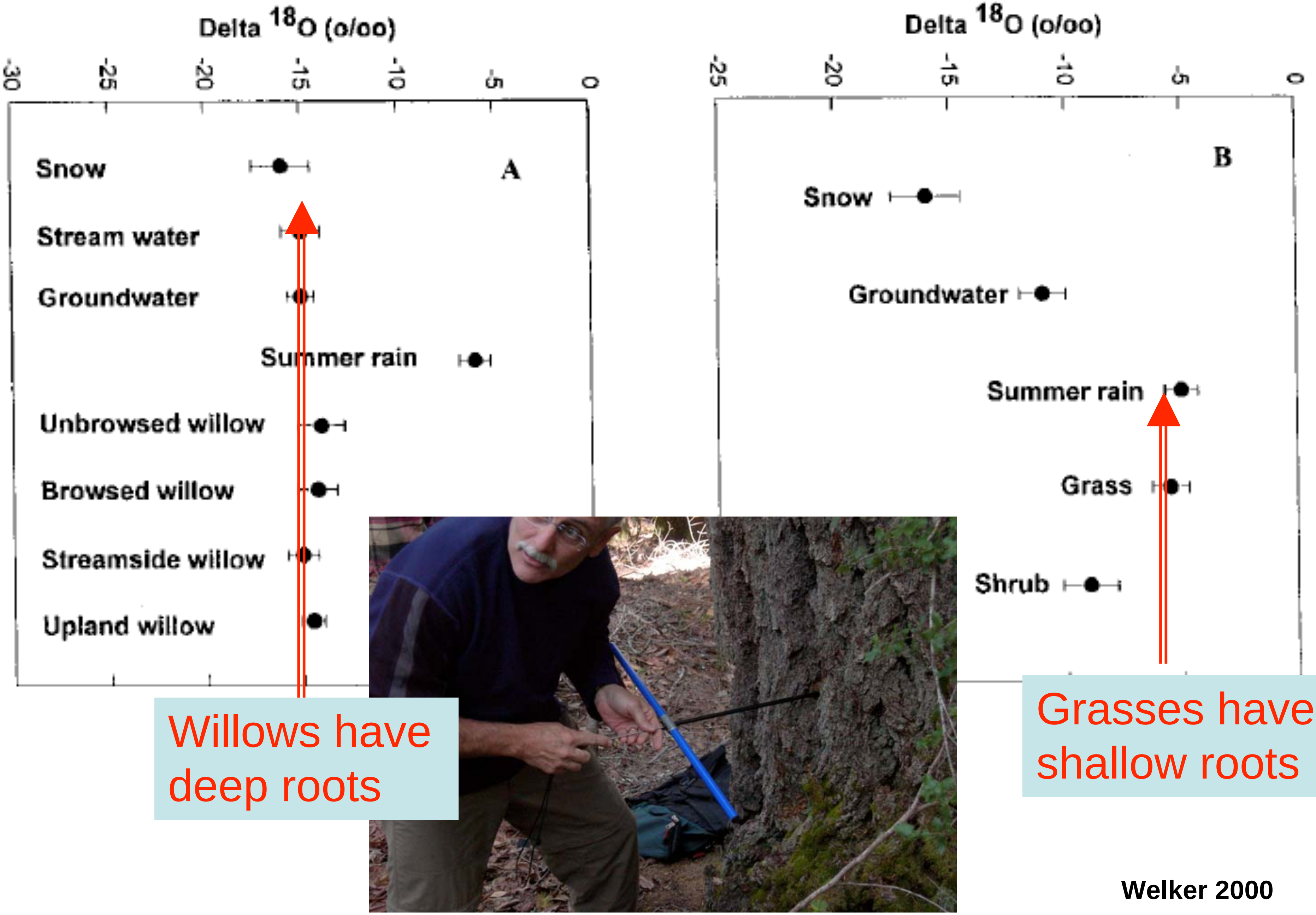


+: water flow to the plant

−: water flow away from the plant

Oliveira *et al.*, 2006

Isotope of vegetation reflect water source

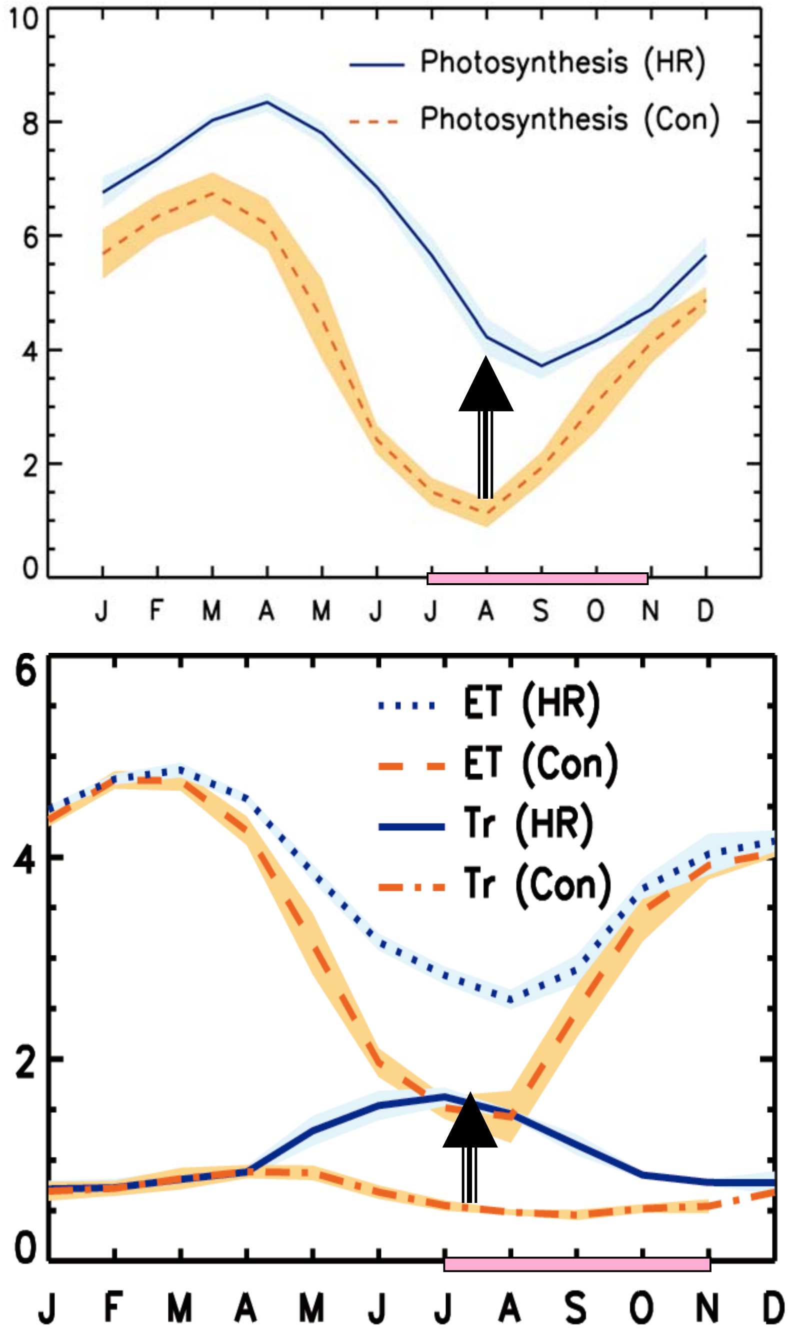


Willows have deep roots

Grasses have shallow roots

Welker 2000

Hydraulic Redistribution in CAM2:



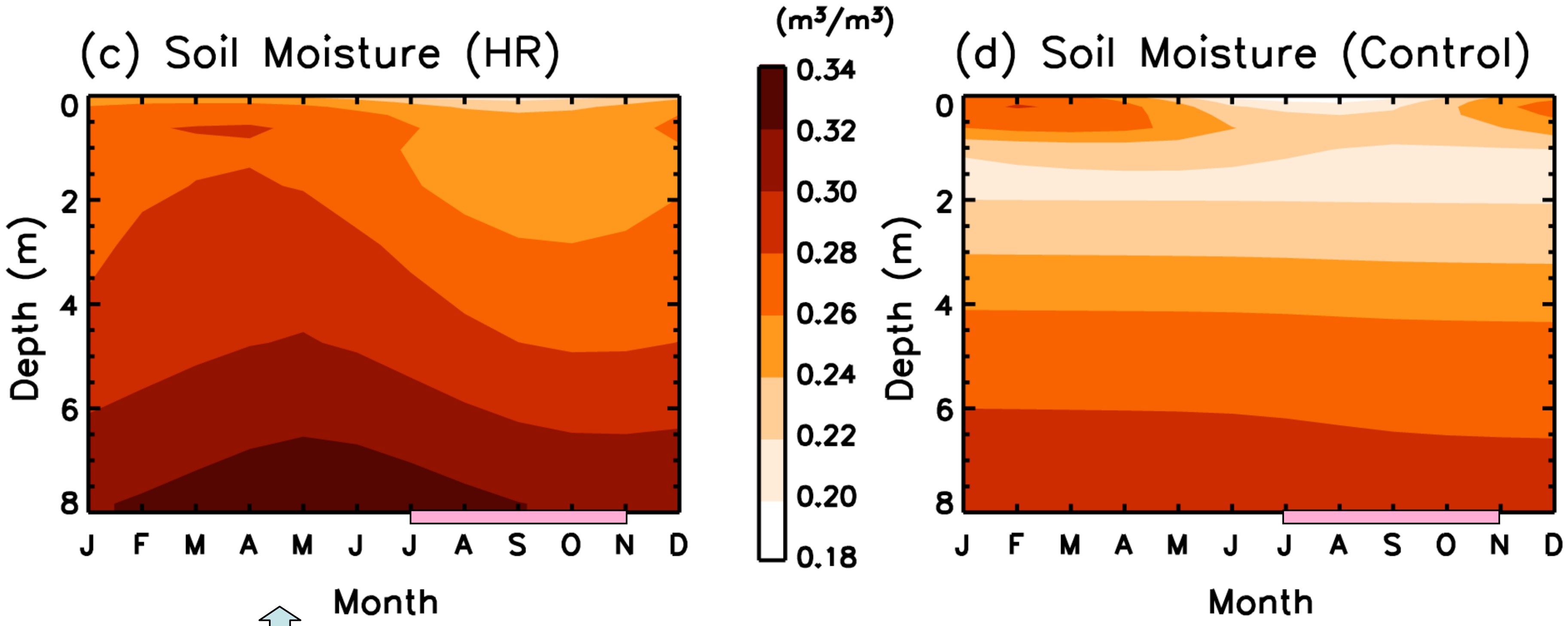
increases photosynthesis and transpiration during the dry season

Lee et al. PNAS 2005 ☺

Seasonality of Soil Moisture

With Hydraulic Redistribution

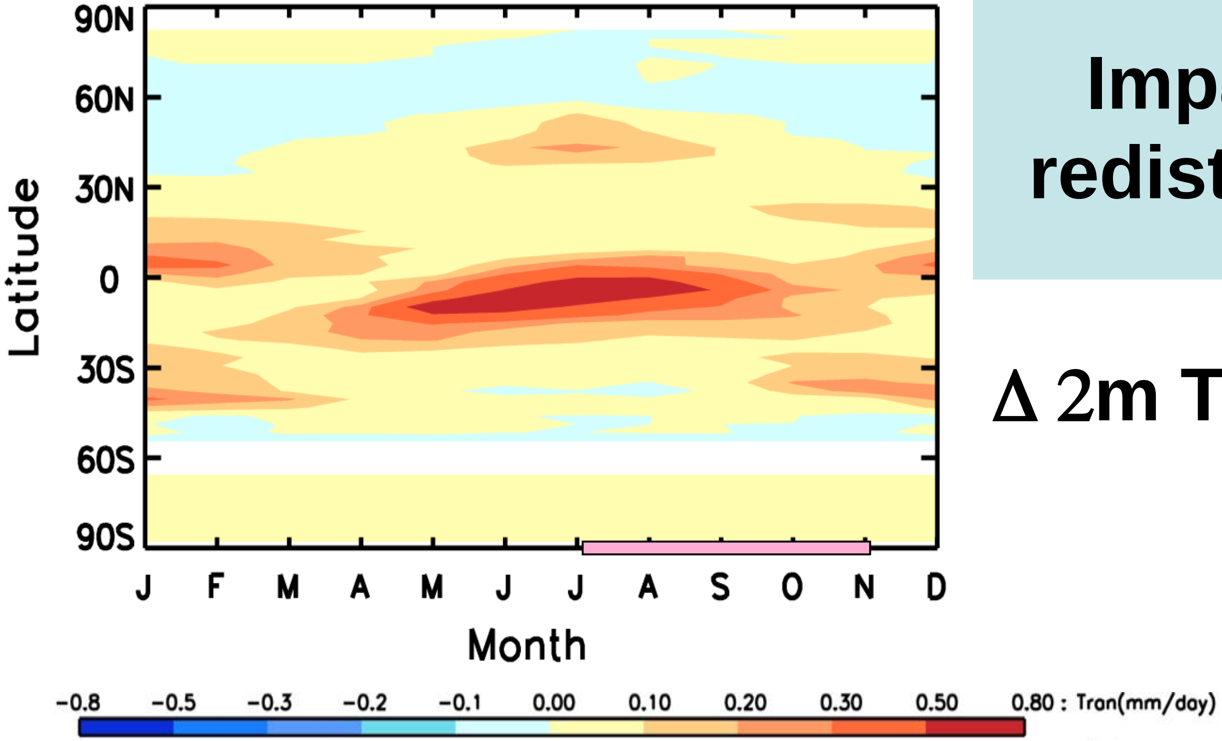
Without Hydraulic Redistribution



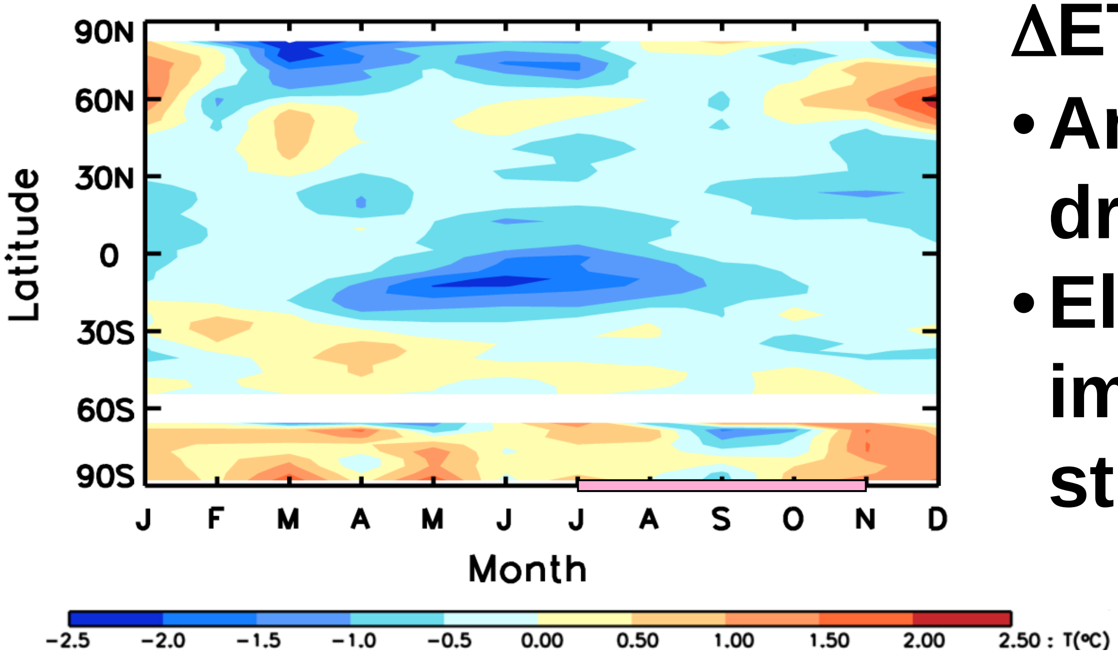
Banking water

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



Δ 2m Temperature



ΔET:

- **Amazon: extends into dry season**
- **Elsewhere: largest impact in water stressed regions**

Lee et al. PNAS 2006

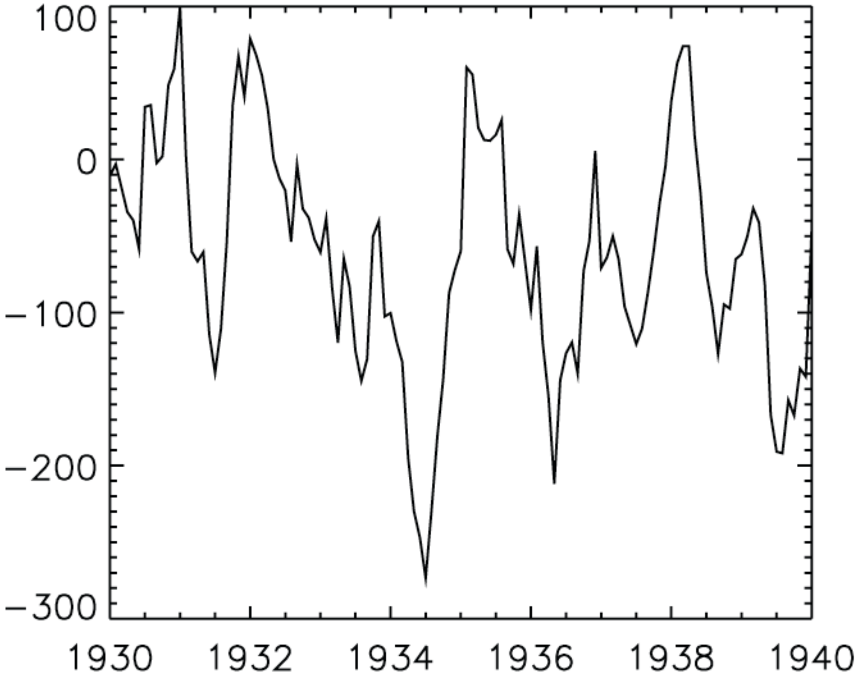
Carbon-Water Coupling

Jung-Eun Lee: Hydraulic Redistribution by Roots

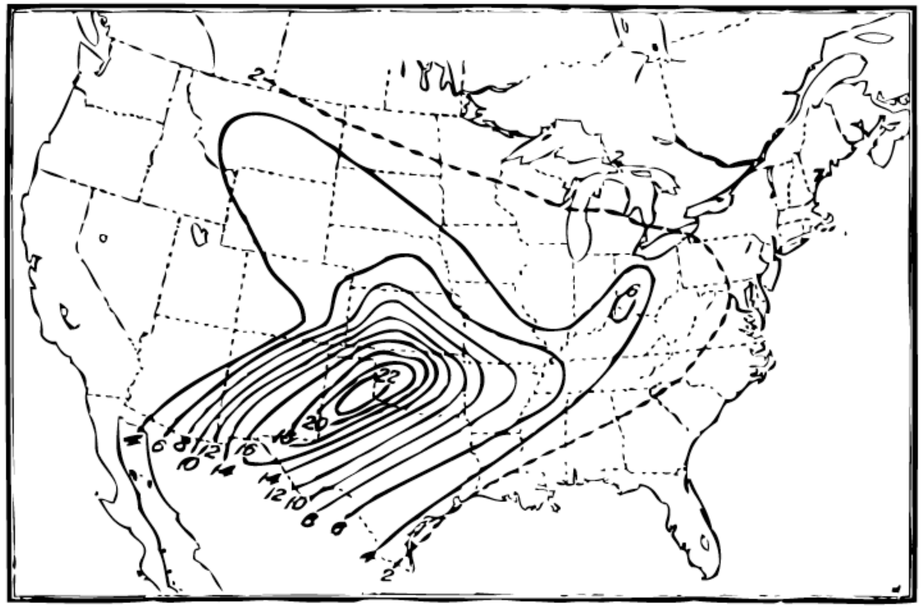
Charlie Koven: Dust Bowl

Case Study: 1930’s dust bowl in US

1930s Great Plains Precipitation Anomalies from Global Historical Climatology Project

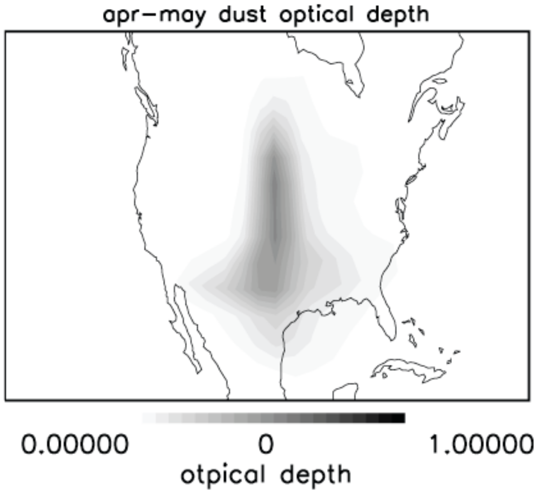


Dust storm frequency, March1936, from Martin (1936)

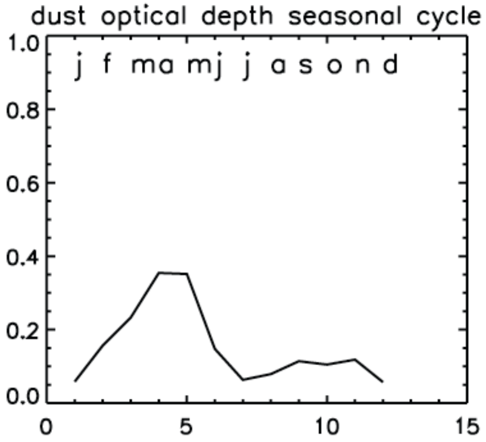


Number of days with duststorms, or dusty conditions, March 1936.—W. A. M

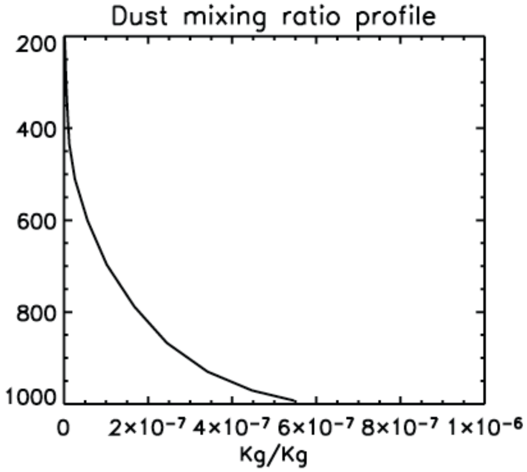
Specify 3D dust distrib from MATCH-DEAD for CAM2 expts



(a) Map of mean dust aot for apr-may

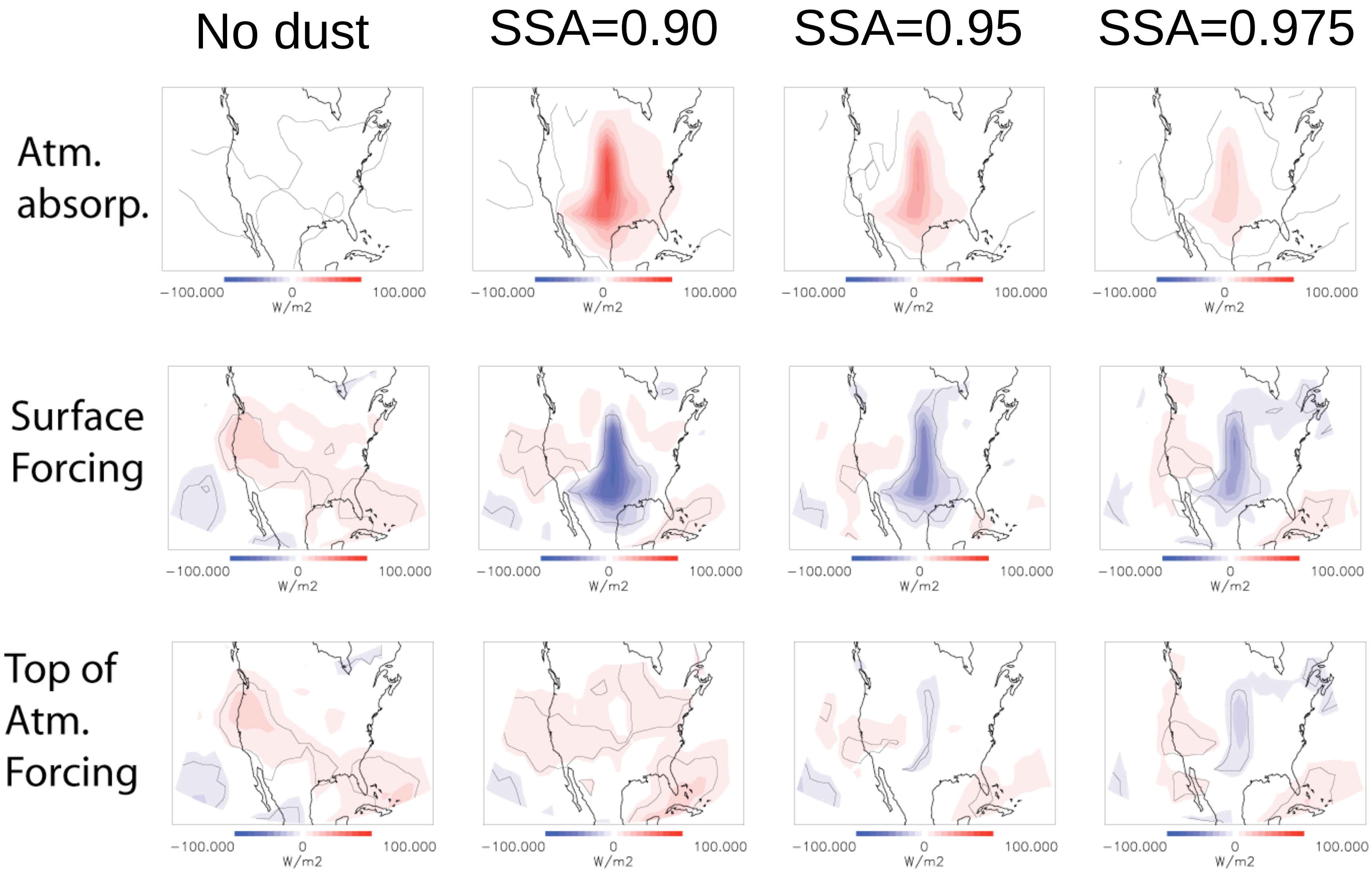


(b) Timeseries of dust aot over dust-bowl region



(c) Profile of dust mass mixing ratio over dustbowl area for months apr-may

Dust Radiative Forcing



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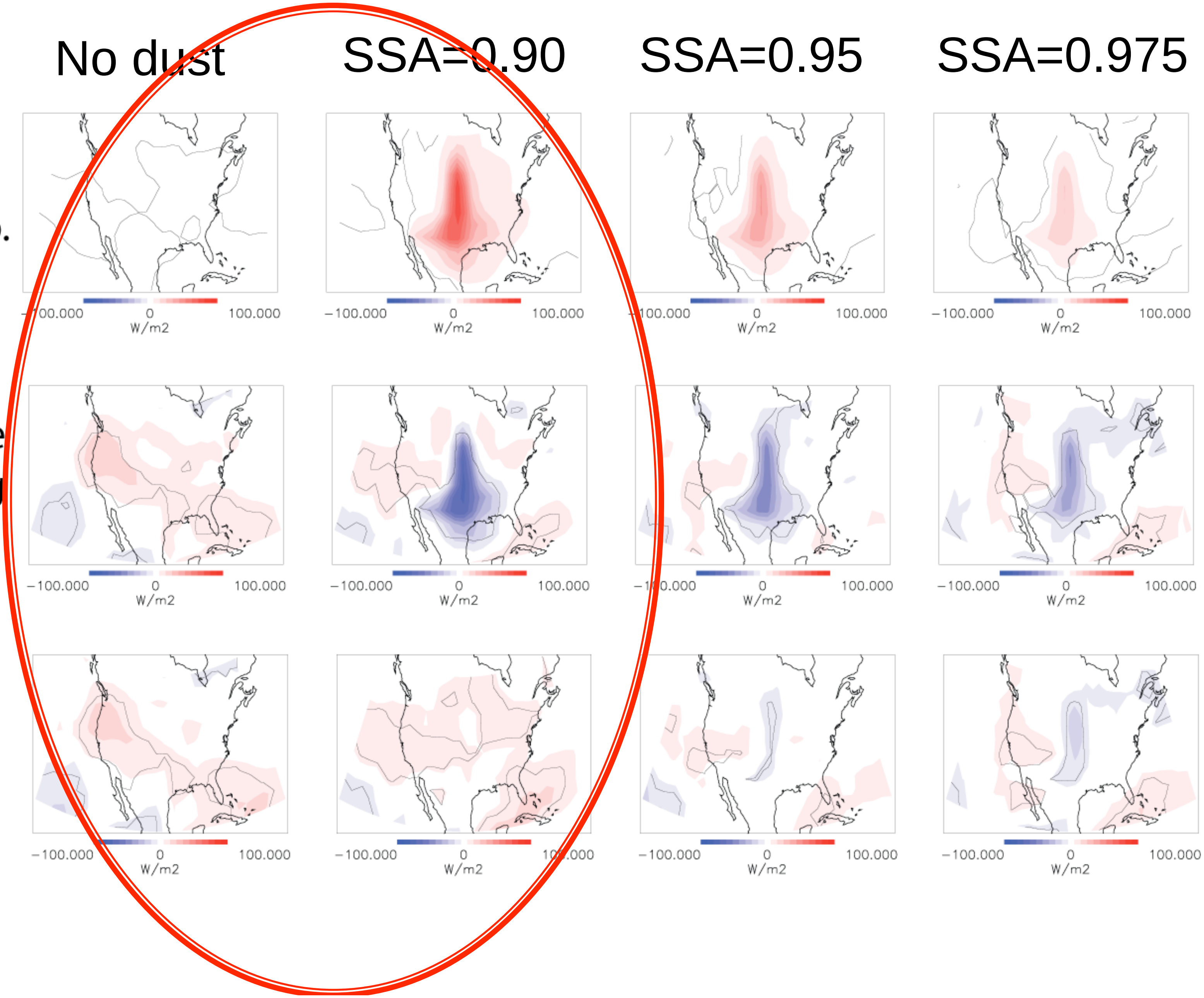
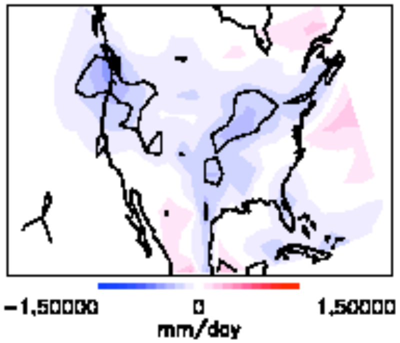
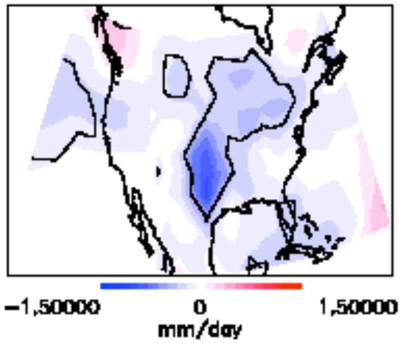


Precip Anomalies, April-May

SSTA



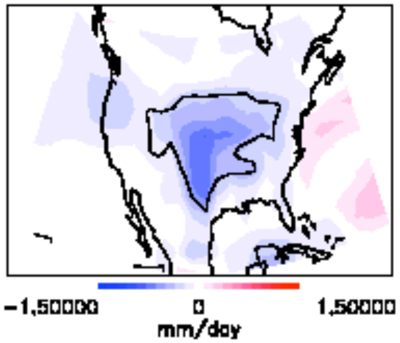
(a) LN-Climo



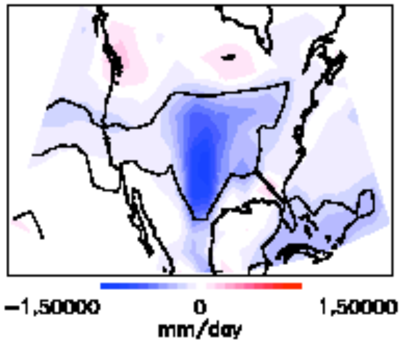
(b) D0LN-Climo

Dust+SSTA

VegA

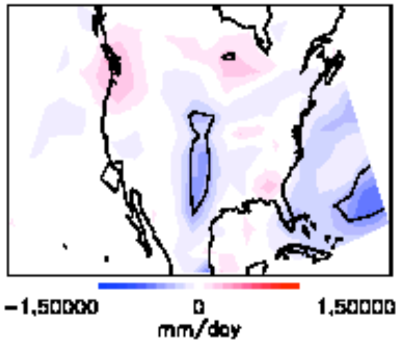


(e) VS-Climo



(f) VSD0LN-Climo

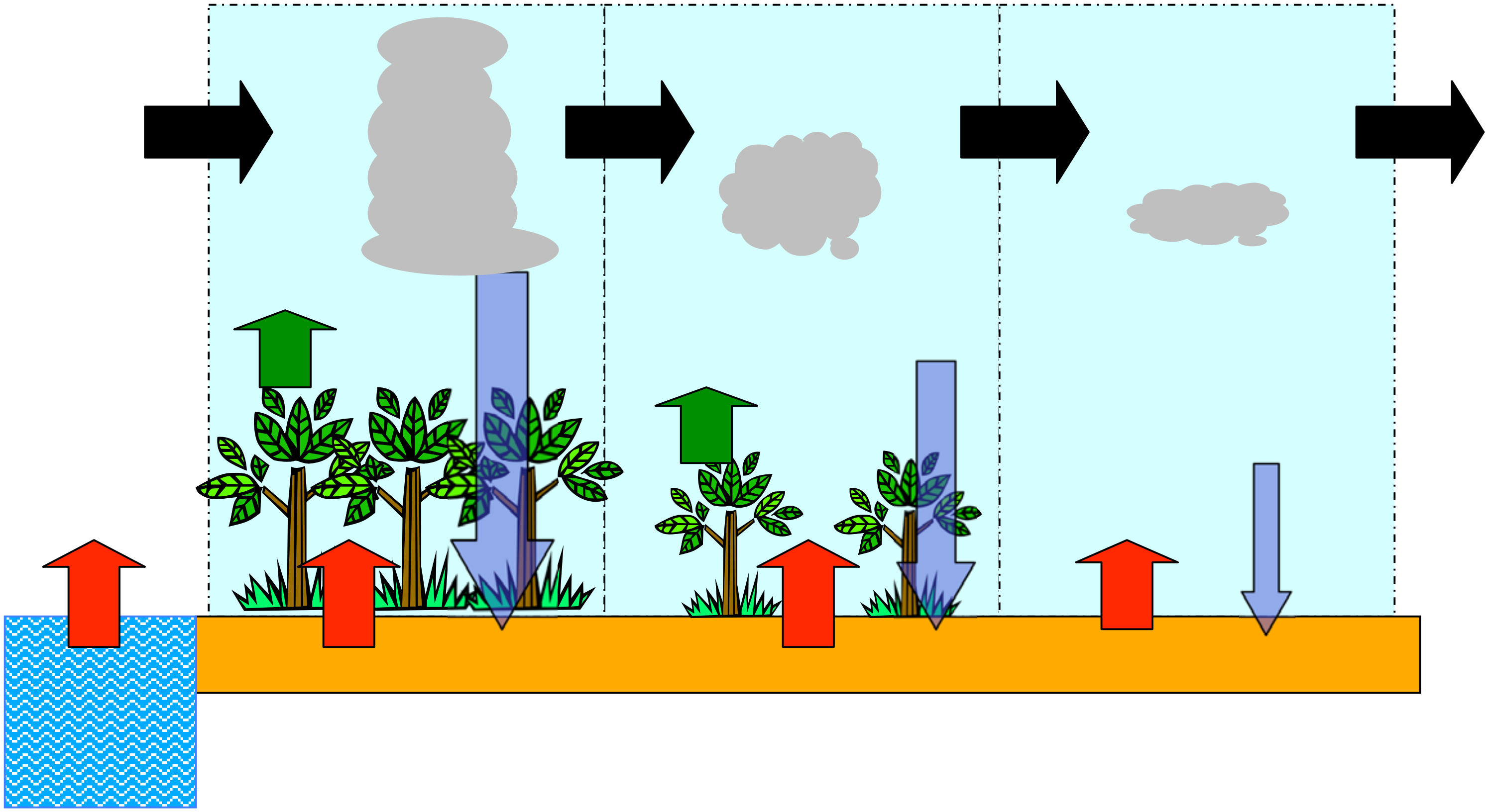
Dust+VegA+SSTA



(i) VSD0LN-VS

Dust+VegA+SSTA –
VegA

The Regional Hydrologic Cycle

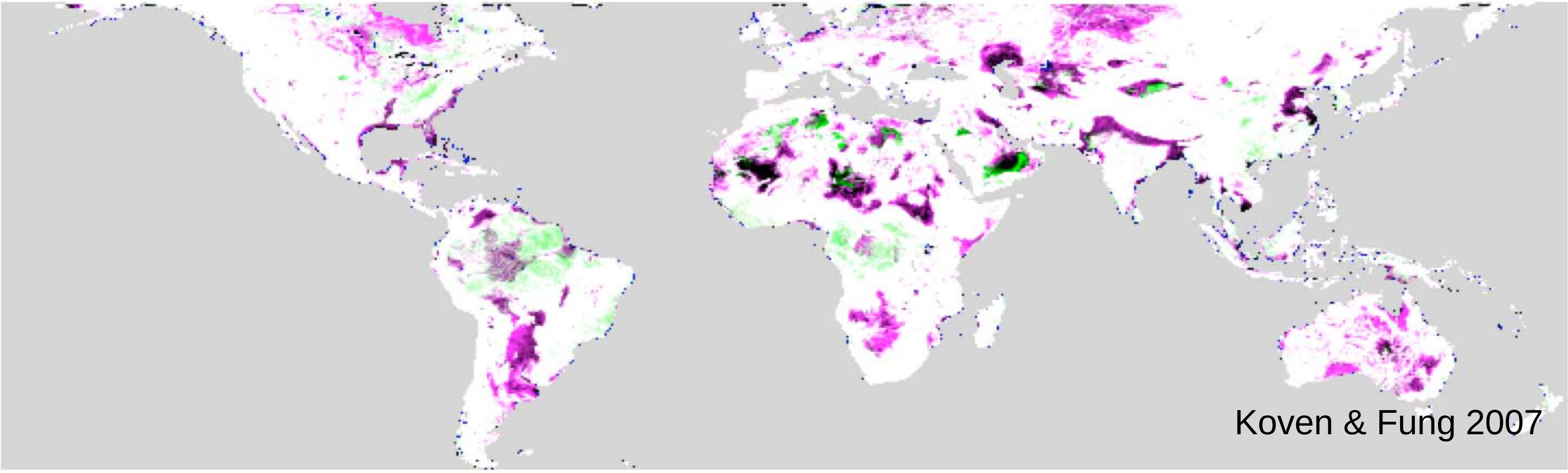


$$\frac{\partial q}{\partial t} = \underbrace{\nabla \bullet (\vec{v}q)}_{remote} + \underbrace{Evap + Transp'n}_{local\ land\ surface} - \underbrace{Condens'n}_{local\ atmosphere}$$

q = water vapor mixing ratio, kg H2O/kg air

Potential Dust Sources

based on slope and roughness


Koven & Fung 2007

Feedback:

drying/ deforestation/ urbanization
→reduce ET
→ further drying
→ more dust
→ further drying …

Carbon-Water Coupling

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Charlie Koven: Dust Bowl

Outlook

Carbon-Water-Dust-Energy Feedbacks

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

Numerical Prediction and the General Circulation

(Charney Oct 26-28, 1955)

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 y 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?

Numerical Prediction and the General Circulation

(Charney Oct 26-28, 1955)

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.