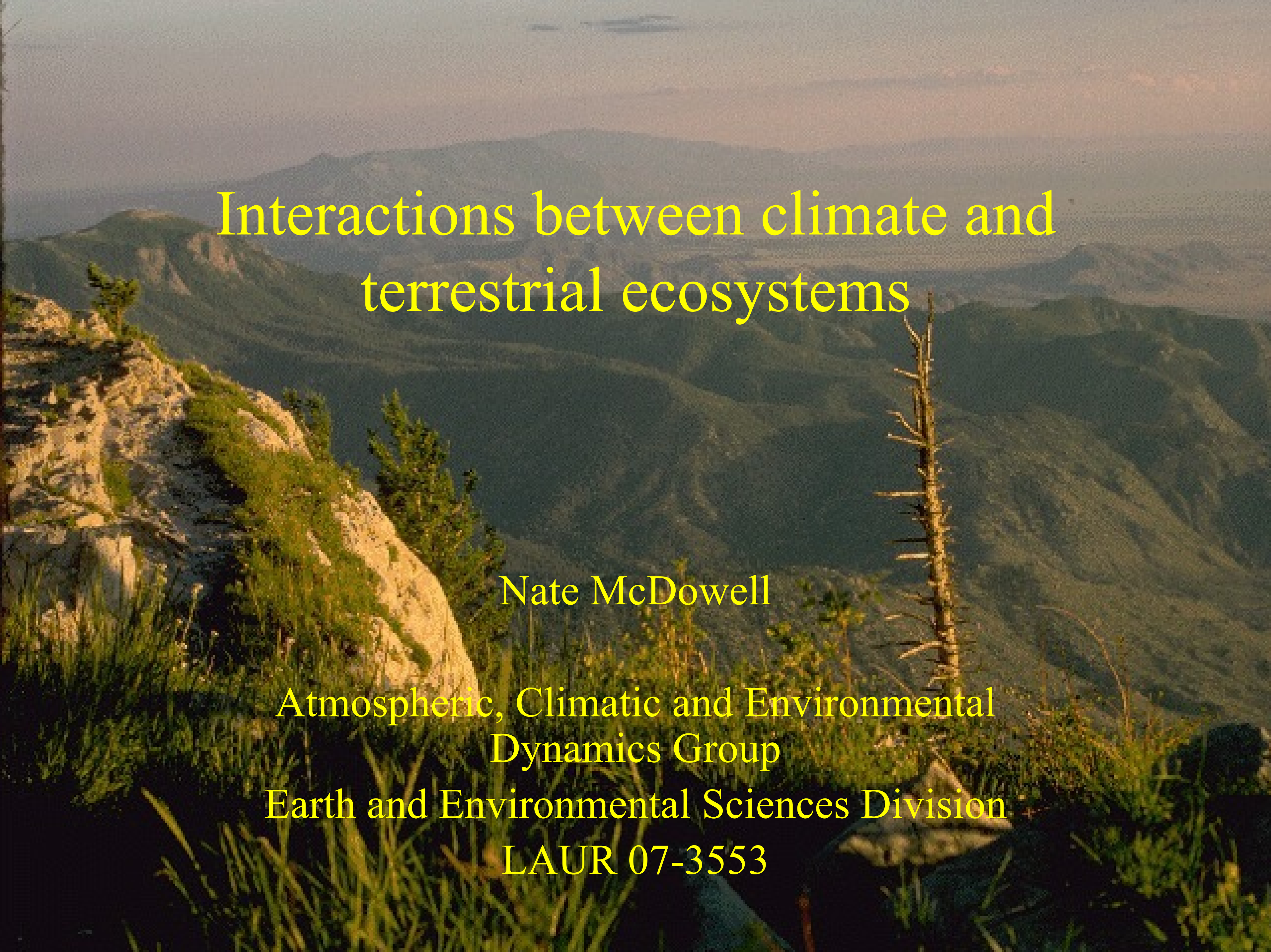


Interactions between climate and terrestrial ecosystems

Nate McDowell

Atmospheric, Climatic and Environmental Dynamics Group
Earth and Environmental Sciences Division
LAUR 07-3553

IGPP climate study group

- “The primary purpose of the Study Group is to provide a forum for scientists across the lab to exchange ideas and form new collaborations. The presentations are meant to be broad enough to engage the wide cross-section of scientists interested in climate change and its impacts.

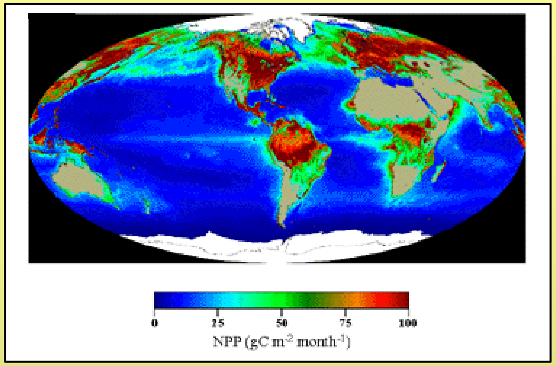
- The group presentations will focus on the following topics: climate change science, linkages between climate change and energy security, and linkages between climate change and socio-economic impacts.”

Biological perspective

- BSc in Biology
- MSc in Forestry-Ecosystem Processes (carbon cycle)
- PhD in Forestry-Tree Physiology, stable isotopes
- Postdoc-Ecosystem-scale stable isotopes

Terrestrial ecosystems: who cares?

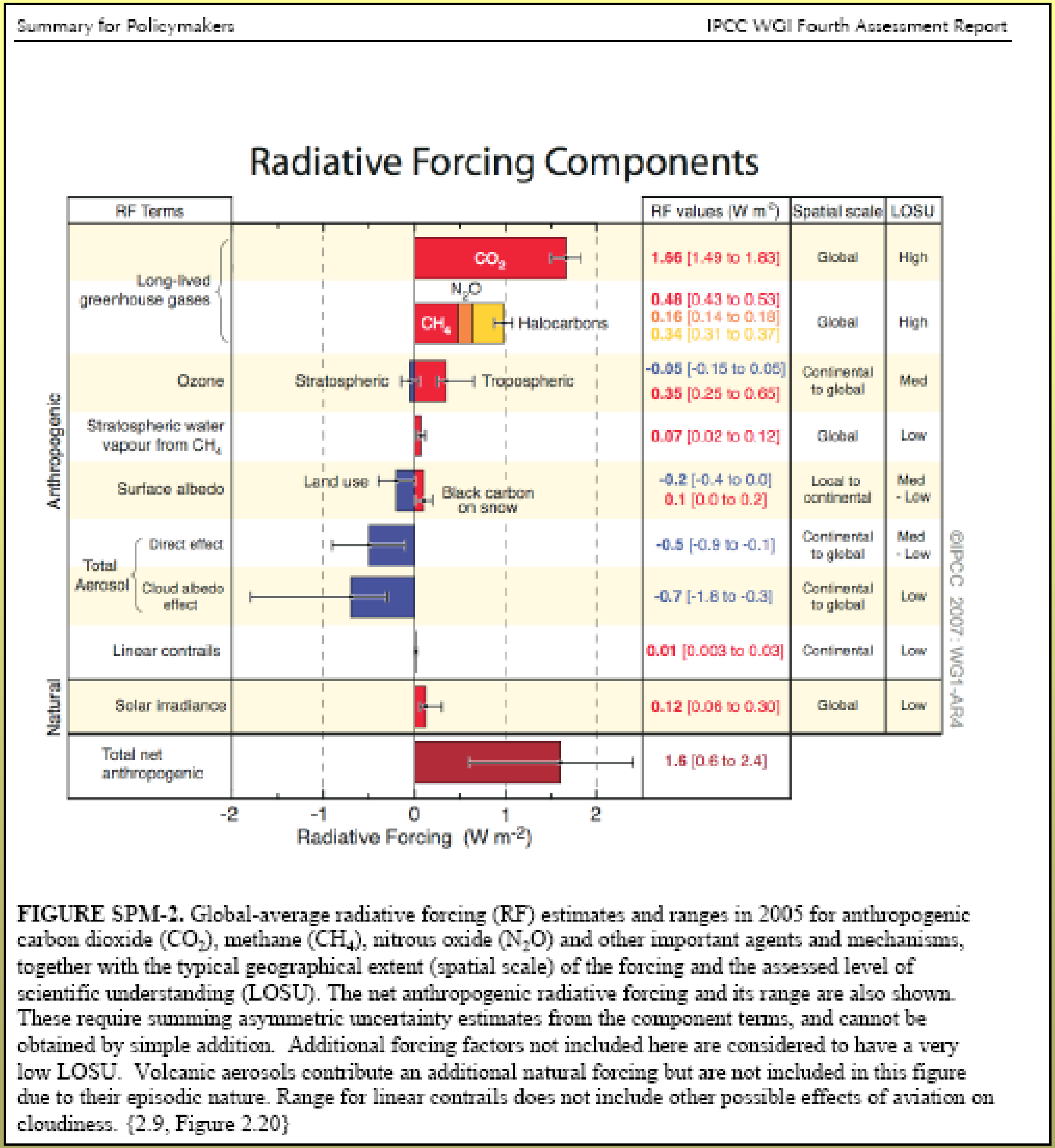
- Major driver of global CO_2, H_2O and energy cycles i.e. major climate driver



- Our primary food source

- Where we live

Terrestrial ecosystems impact many primary climate drivers



Summary for Policymakers

IPCC WGI Fourth Assessment Report

Radiative Forcing Components

	RF Terms		RF values (W m^{-2})	Spatial scale	LOSU
Anthropogenic	Long-lived greenhouse gases	CO_2	1.66 [1.49 to 1.83]	Global	High
		CH_4 N_2O Halocarbons	0.48 [0.43 to 0.53] 0.16 [0.14 to 0.18] 0.34 [0.31 to 0.37]	Global	High
	Ozone	Stratospheric Tropospheric	-0.05 [-0.15 to 0.05] 0.35 [0.25 to 0.65]	Continental to global	Med
	Stratospheric water vapour from CH_4		0.07 [0.02 to 0.12]	Global	Low
	Surface albedo	Land use Black carbon on snow	-0.2 [-0.4 to 0.0] 0.1 [0.0 to 0.2]	Local to continental	Med - Low
	Total Aerosol	Direct effect	-0.5 [-0.9 to -0.1]	Continental to global	Med - Low
		Cloud albedo effect	-0.7 [-1.8 to -0.3]	Continental to global	Low
	Linear contrails		0.01 [0.003 to 0.03]	Continental	Low
Natural	Solar irradiance		0.12 [0.06 to 0.30]	Global	Low
	Total net anthropogenic		1.6 [0.6 to 2.4]		

FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}

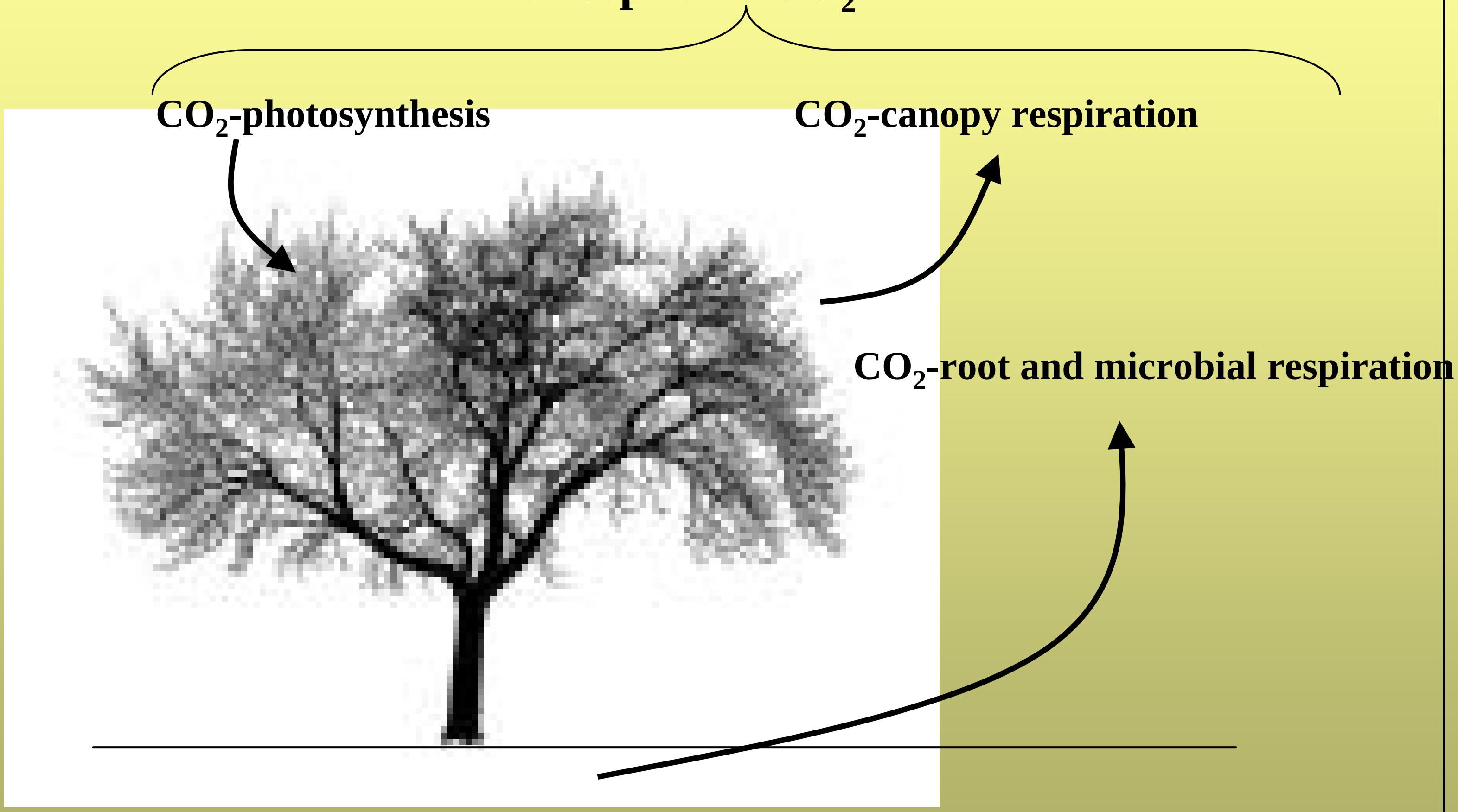
“Bottom-up” climate forcing

Terrestrial exchange of CO_2, H_2O and sensible heat are drivers of local climate

Narisma, et al., 2003. The role of biospheric feedbacks in the simulation of the impact of historical land cover change on the Australian January climate. *Geophys. Res. Letts.*, 30: 2168

Terrestrial carbon cycle.

Plant biomass production = photosynthesis - respiration



Atmospheric CO_2

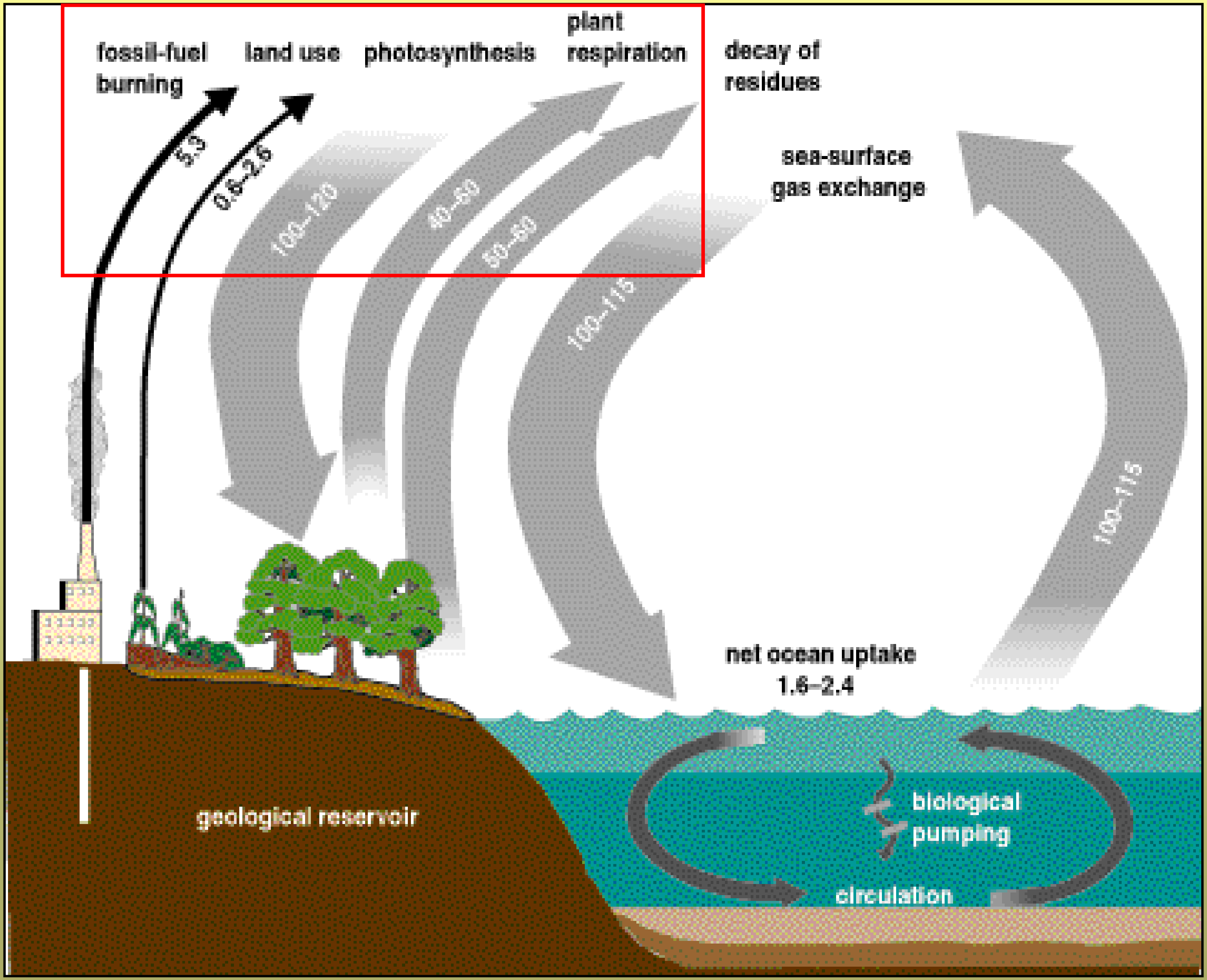
CO_2-photosynthesis

CO_2-canopy respiration

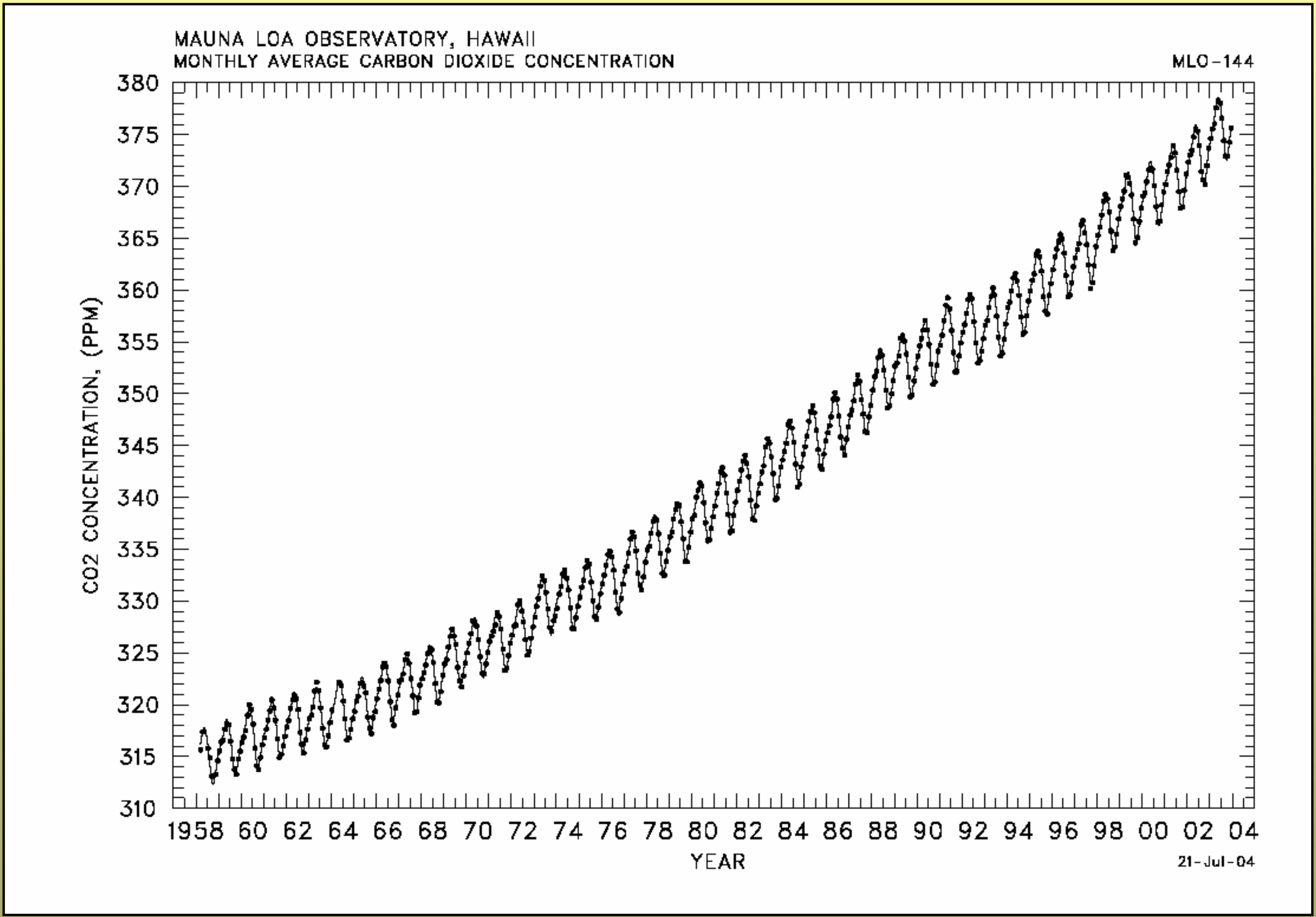
CO_2-root and microbial respiration

Net ecosystem-atmosphere CO_2 flux =
photosynthesis – plant respiration – microbial respiration (decomposition)

The global carbon cycle



Terrestrial ecosystems are currently a carbon sink



Annual cycle of C uptake and release

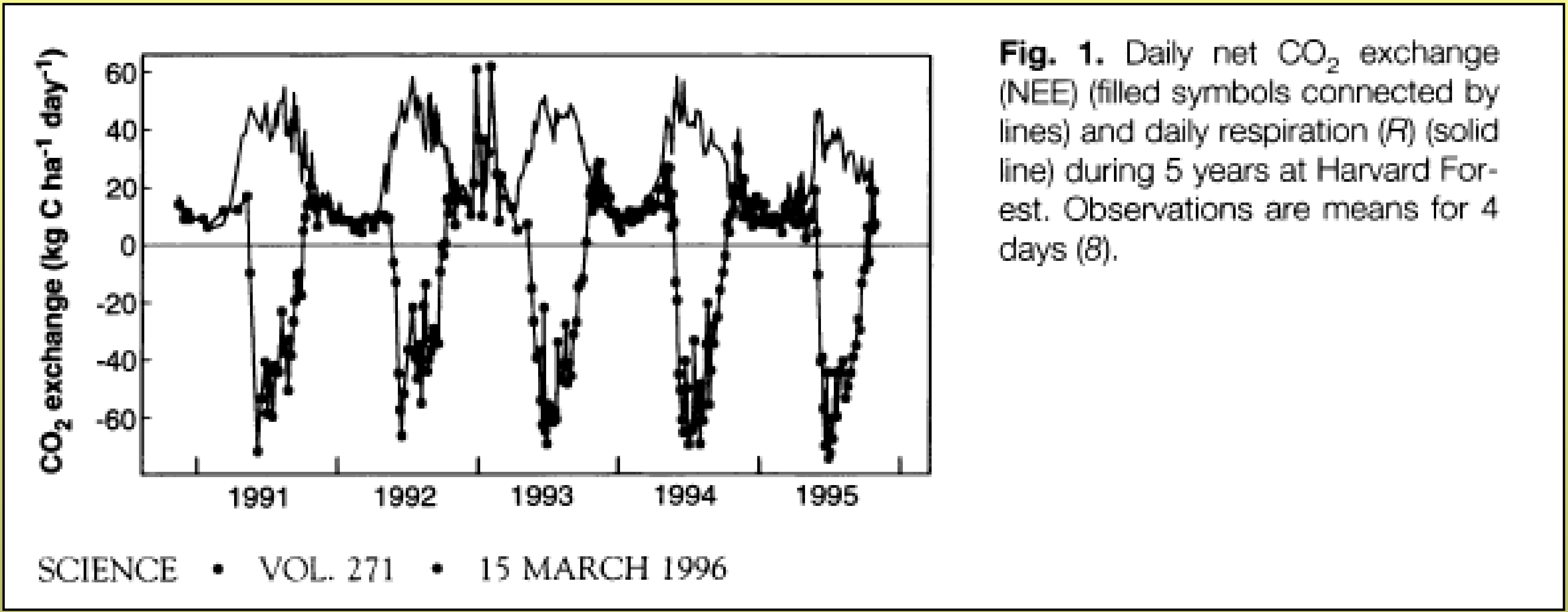


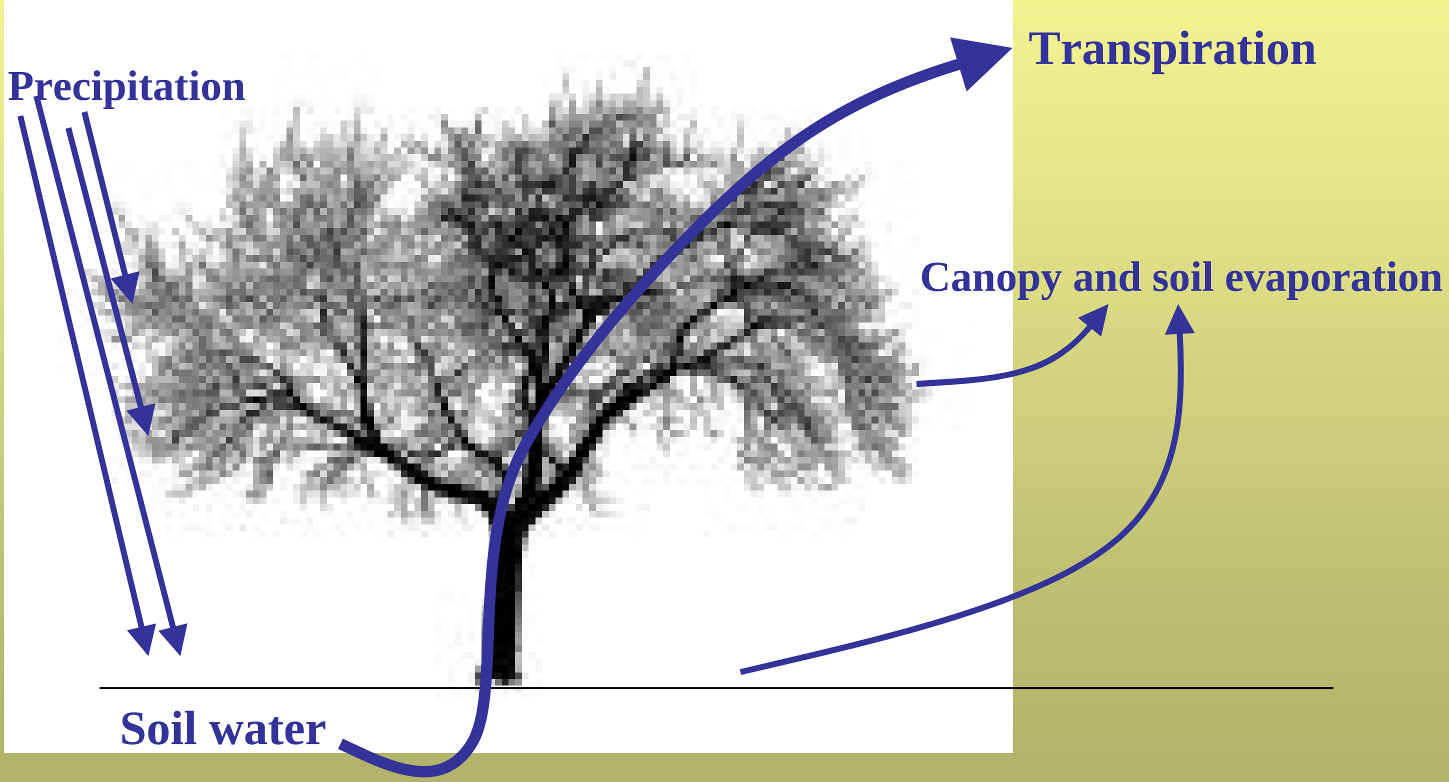
Fig. 1. Daily net CO$_2$ exchange (NEE) (filled symbols connected by lines) and daily respiration (*R*) (solid line) during 5 years at Harvard Forest. Observations are means for 4 days (*8*).

SCIENCE • VOL. 271 • 15 MARCH 1996

Goulden et al. 1996. Exchange of carbon dioxide by a deciduous forest: Response to inter-annual climate variability. *Science* 271: 1576-1578

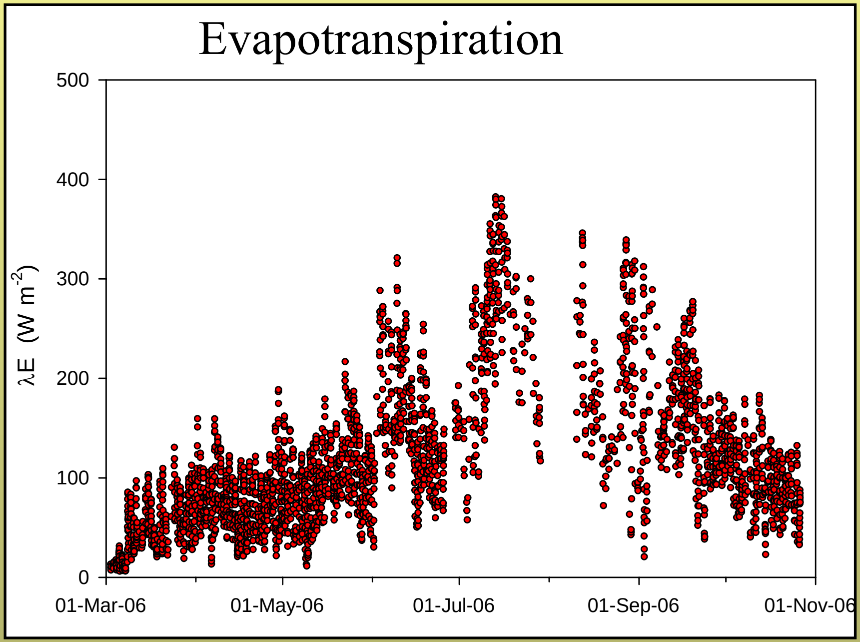
Terrestrial water cycle.

Water storage = precipitation – evaporation and transpiration

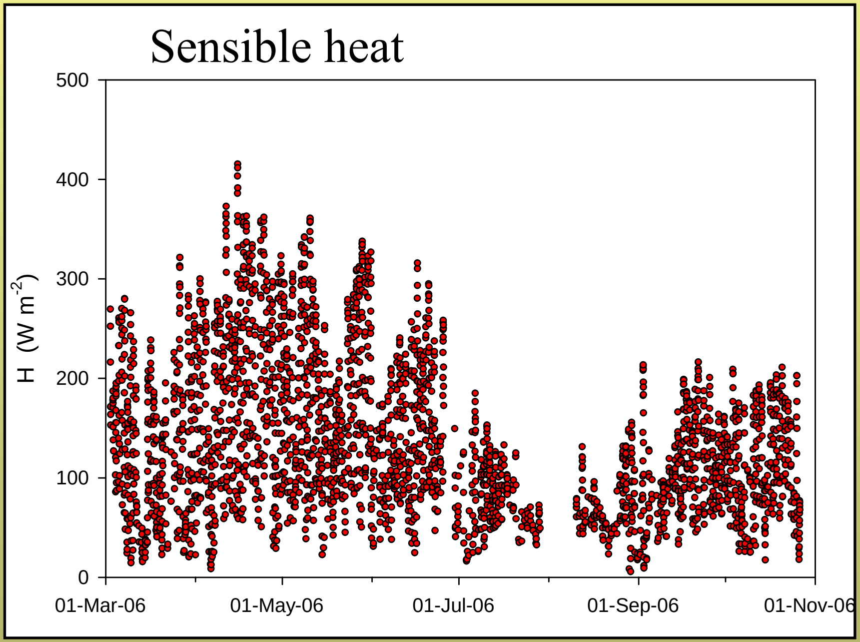


Net ecosystem-atmosphere H_2O flux =
Precipitation– plant transpiration – canopy and soil evaporation – run-off

Annual evapotranspiration and sensible heat



Evapotranspiration



Sensible heat

Valle Grande grassland, 2006 Rahn and McCabe 2006

Need to consider all impacts of ecosystems on climate

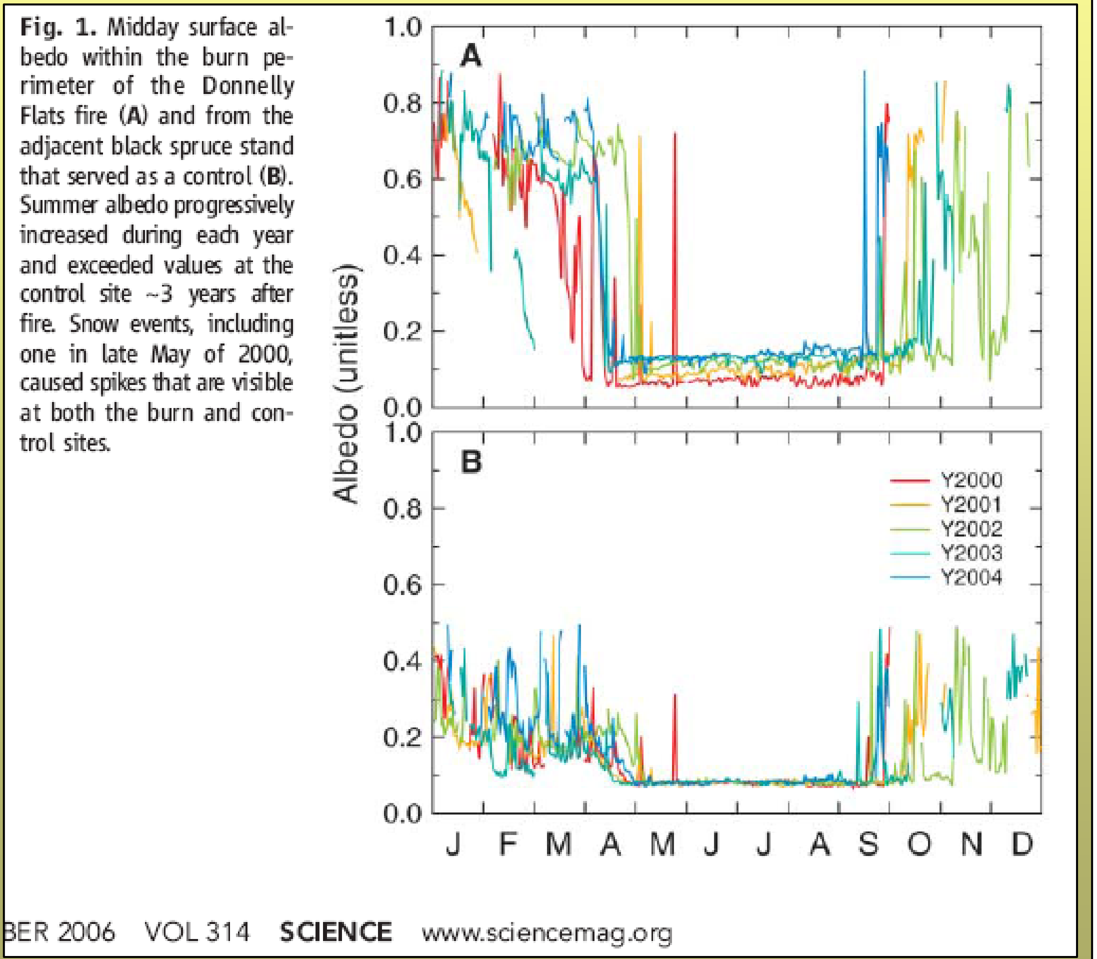


Fig. 1. Midday surface albedo within the burn perimeter of the Donnelly Flats fire (**A**) and from the adjacent black spruce stand that served as a control (**B**). Summer albedo progressively increased during each year and exceeded values at the control site ~3 years after fire. Snow events, including one in late May of 2000, caused spikes that are visible at both the burn and control sites.

BER 2006 VOL 314 **SCIENCE** www.sciencemag.org

Randerson et al. 2006 The impact of boreal forest fire on climate warming *Science* 314: 1130-1132

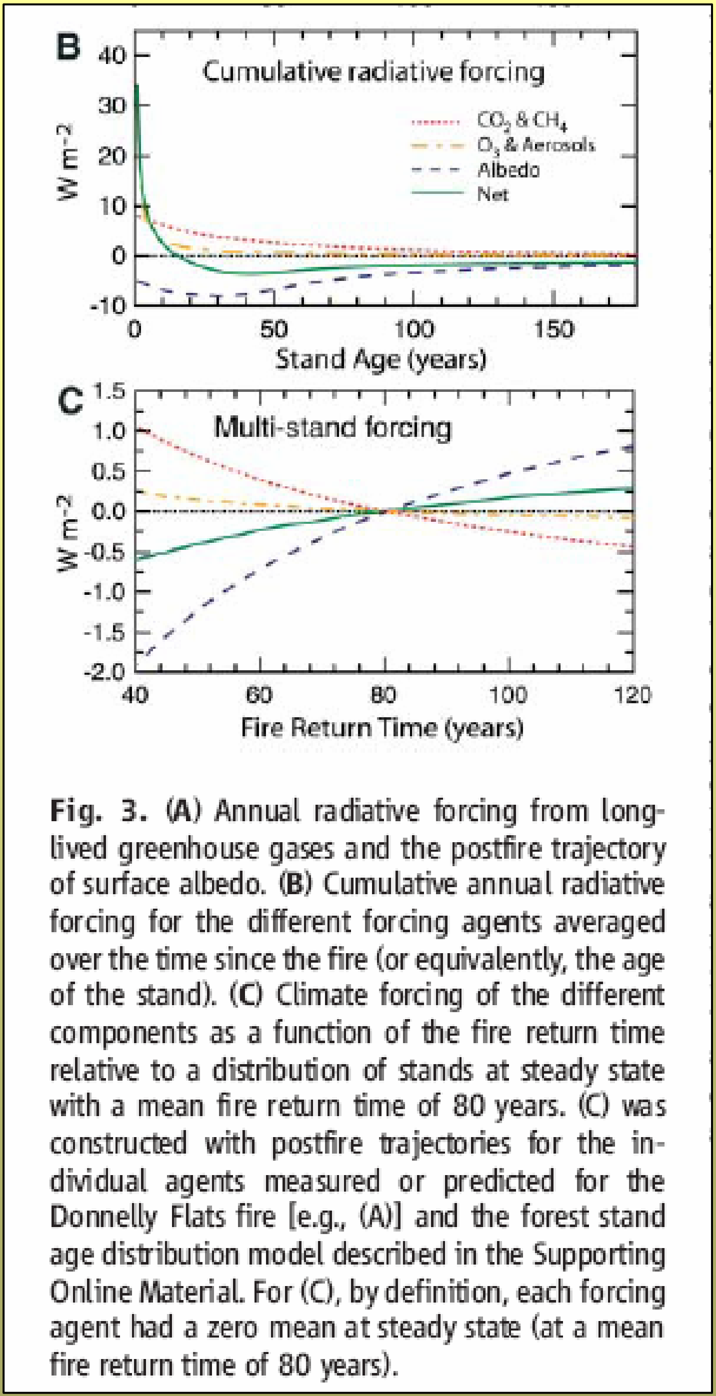
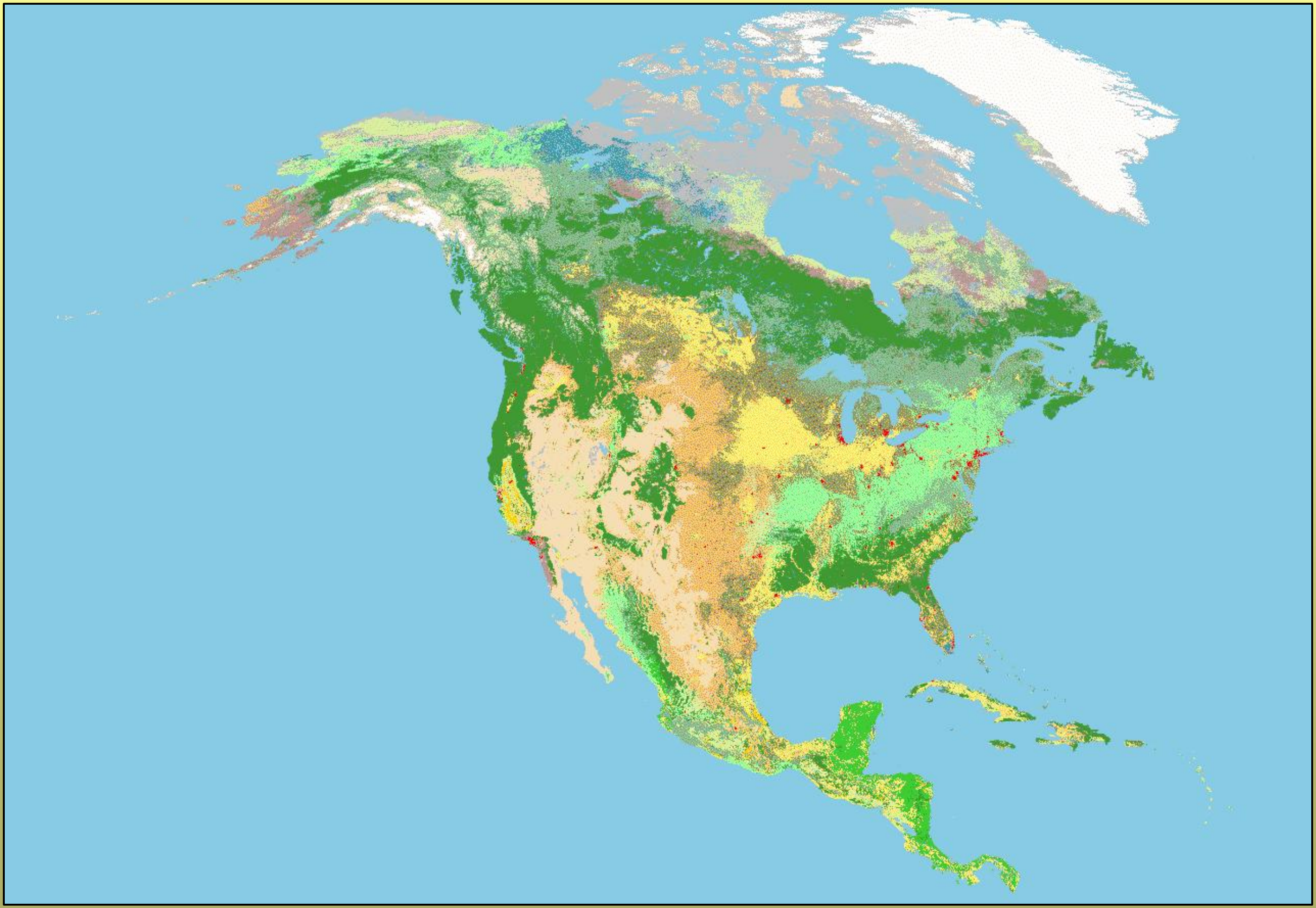
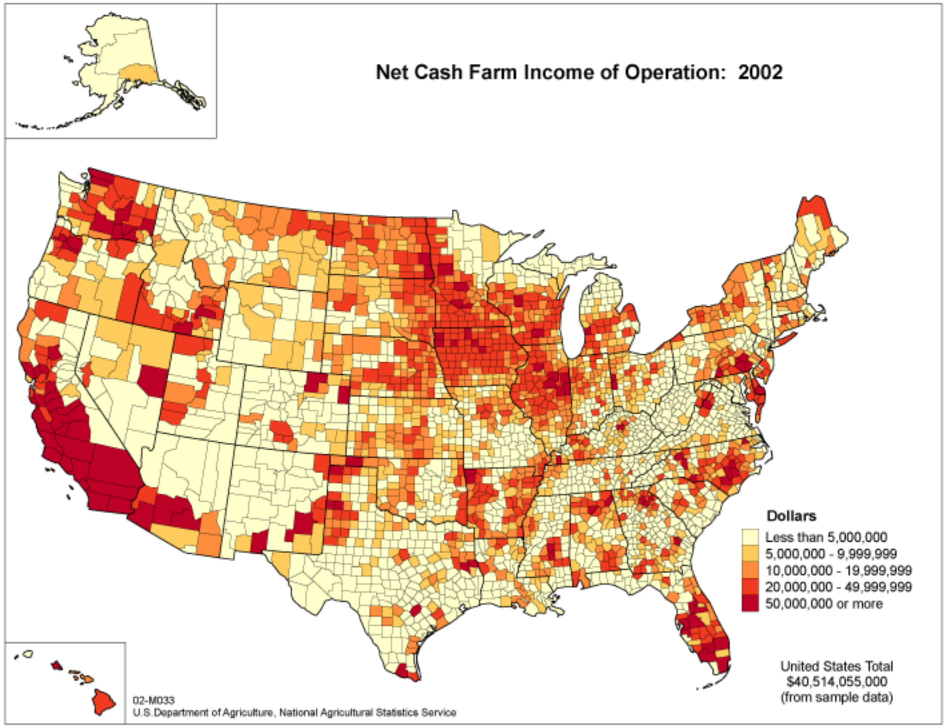


Fig. 3. (**A**) Annual radiative forcing from long-lived greenhouse gases and the postfire trajectory of surface albedo. (**B**) Cumulative annual radiative forcing for the different forcing agents averaged over the time since the fire (or equivalently, the age of the stand). (**C**) Climate forcing of the different components as a function of the fire return time relative to a distribution of stands at steady state with a mean fire return time of 80 years. (C) was constructed with postfire trajectories for the individual agents measured or predicted for the Donnelly Flats fire [e.g., (A)] and the forest stand age distribution model described in the Supporting Online Material. For (C), by definition, each forcing agent had a zero mean at steady state (at a mean fire return time of 80 years).

Climate impacts on terrestrial ecosystems

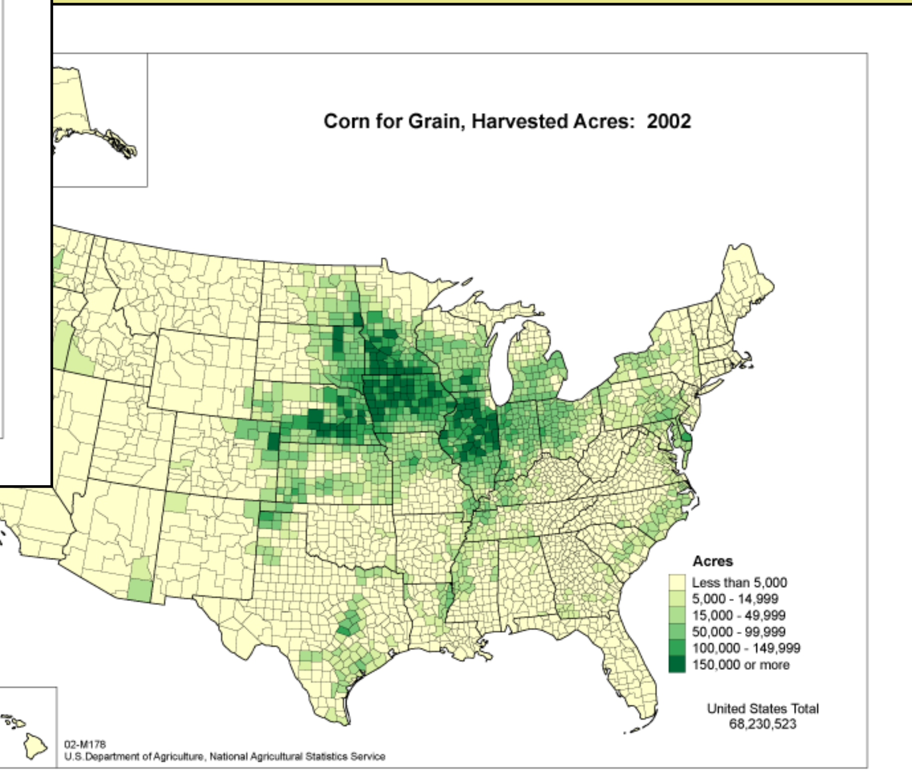


Regional Climate Impacts

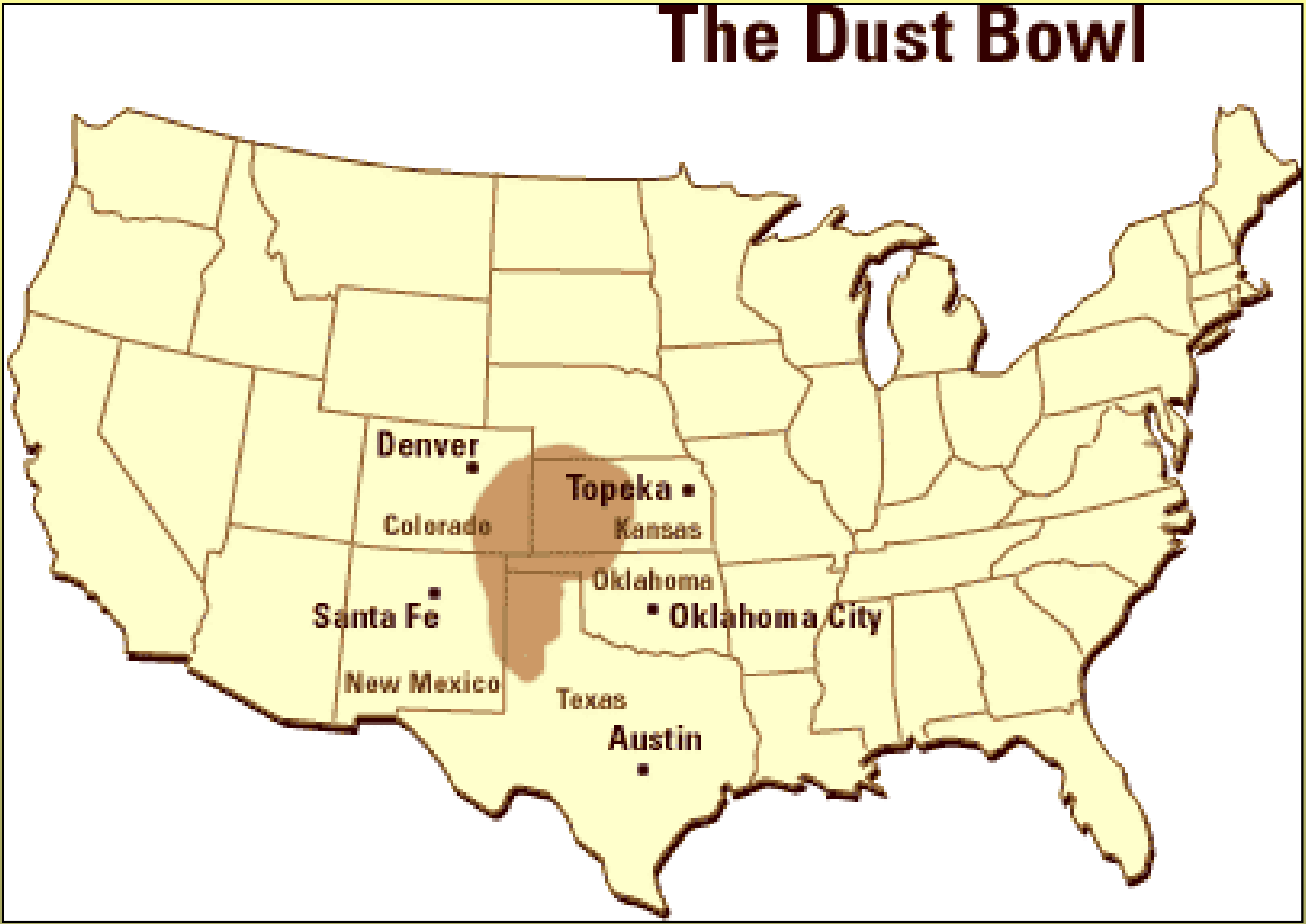


Net annual income all crops

Corn annual harvested acres

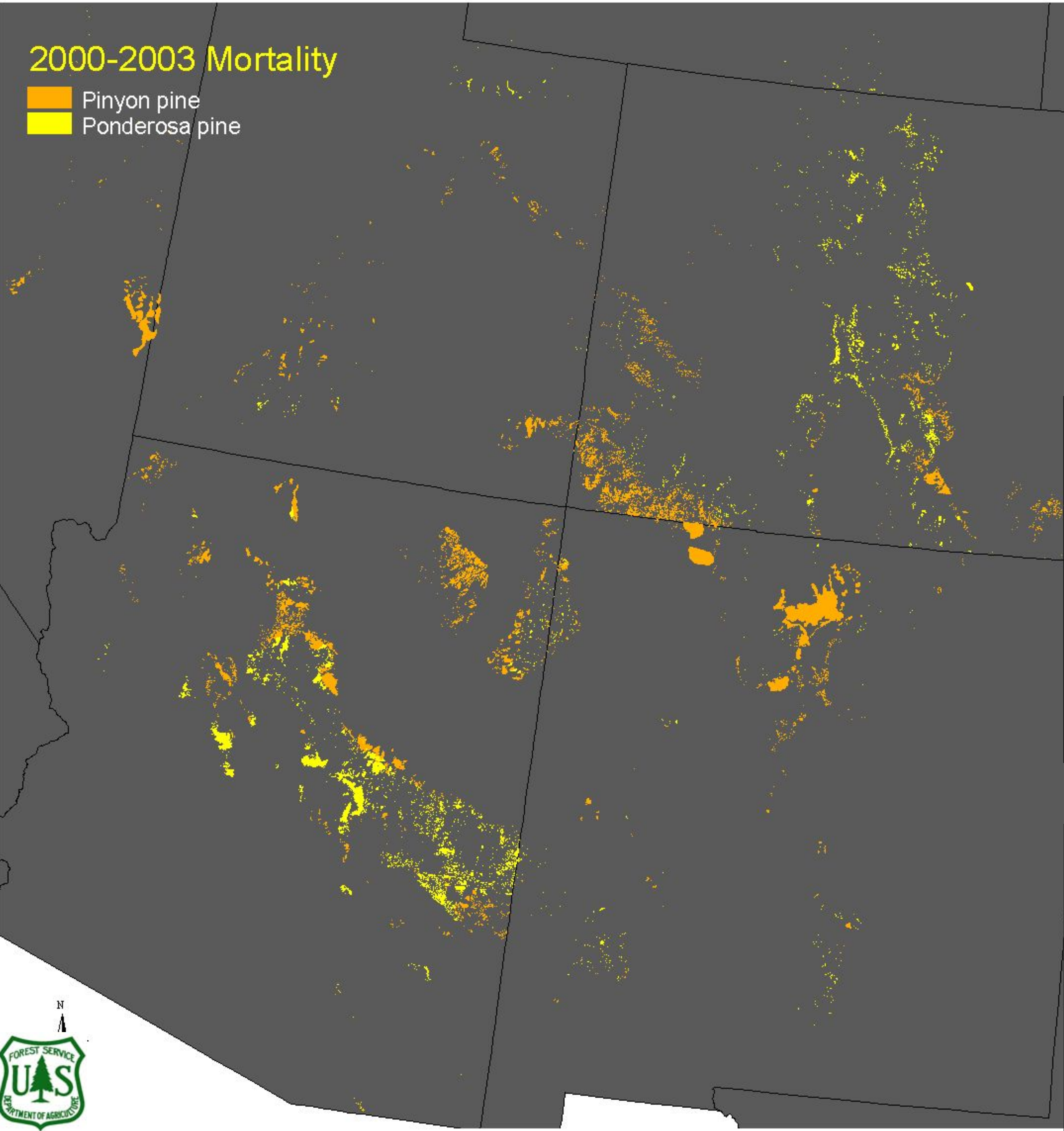


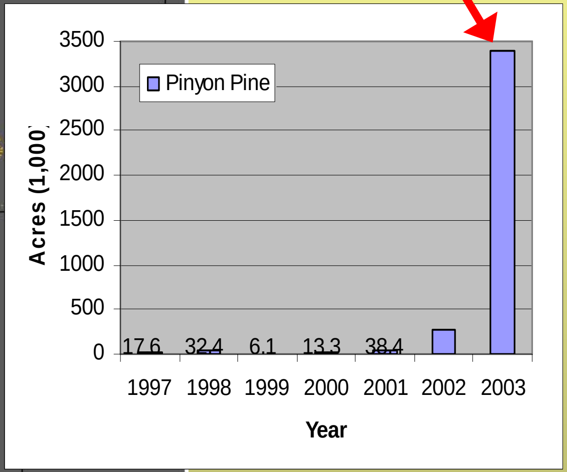
Regional climate impacts

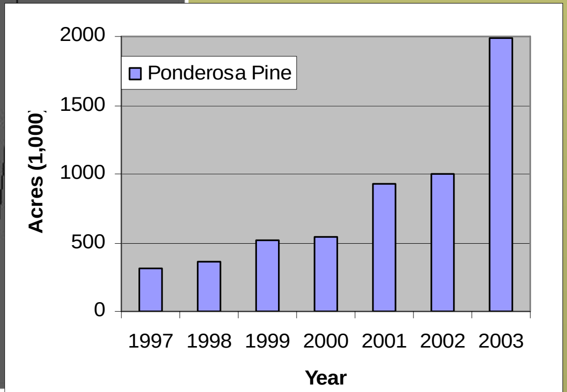


Regional climate change-Southwest

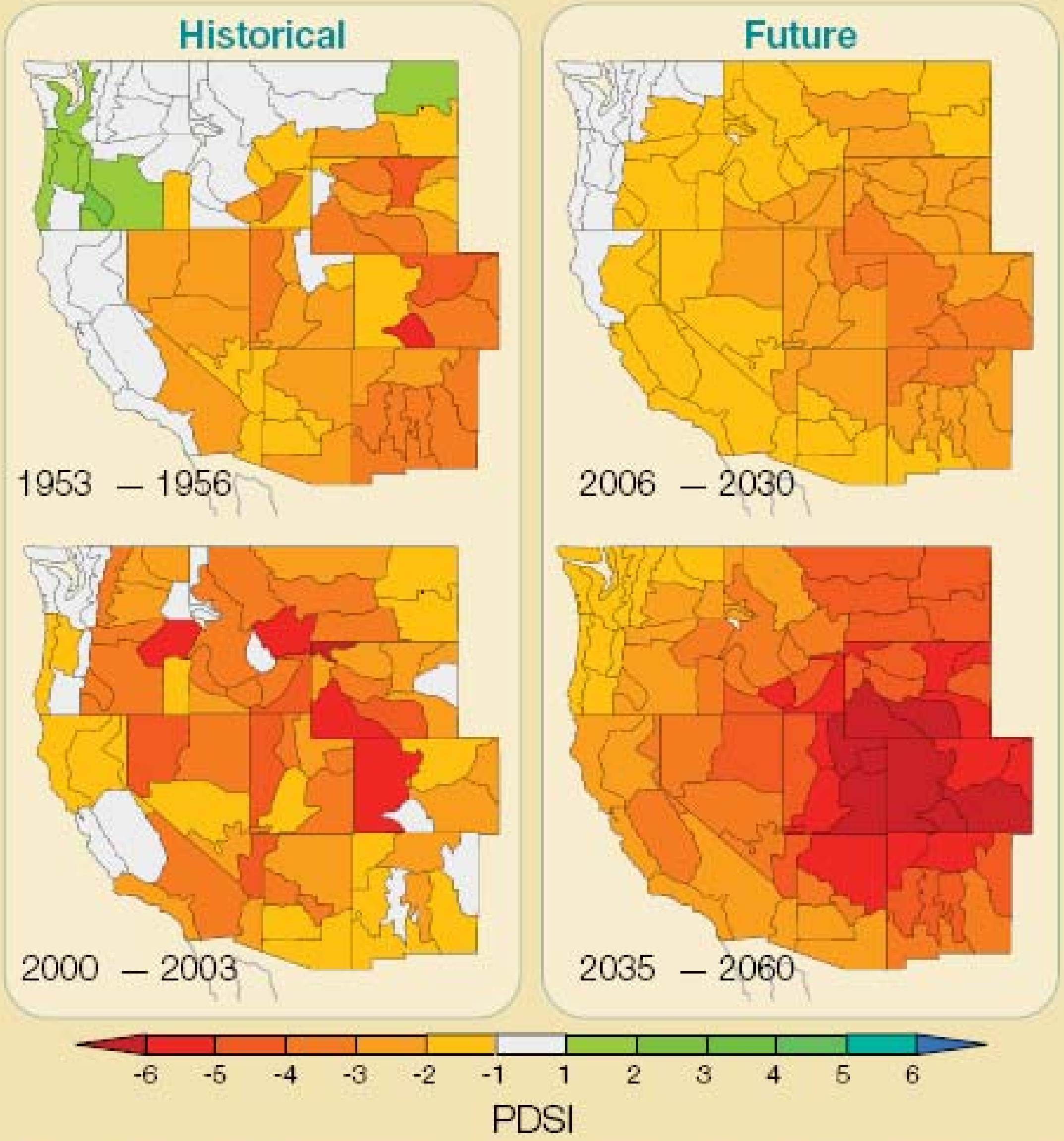
USFS aerial surveys for insect and disease, cumulative map of affected areas in Southwest for 2000-2003.





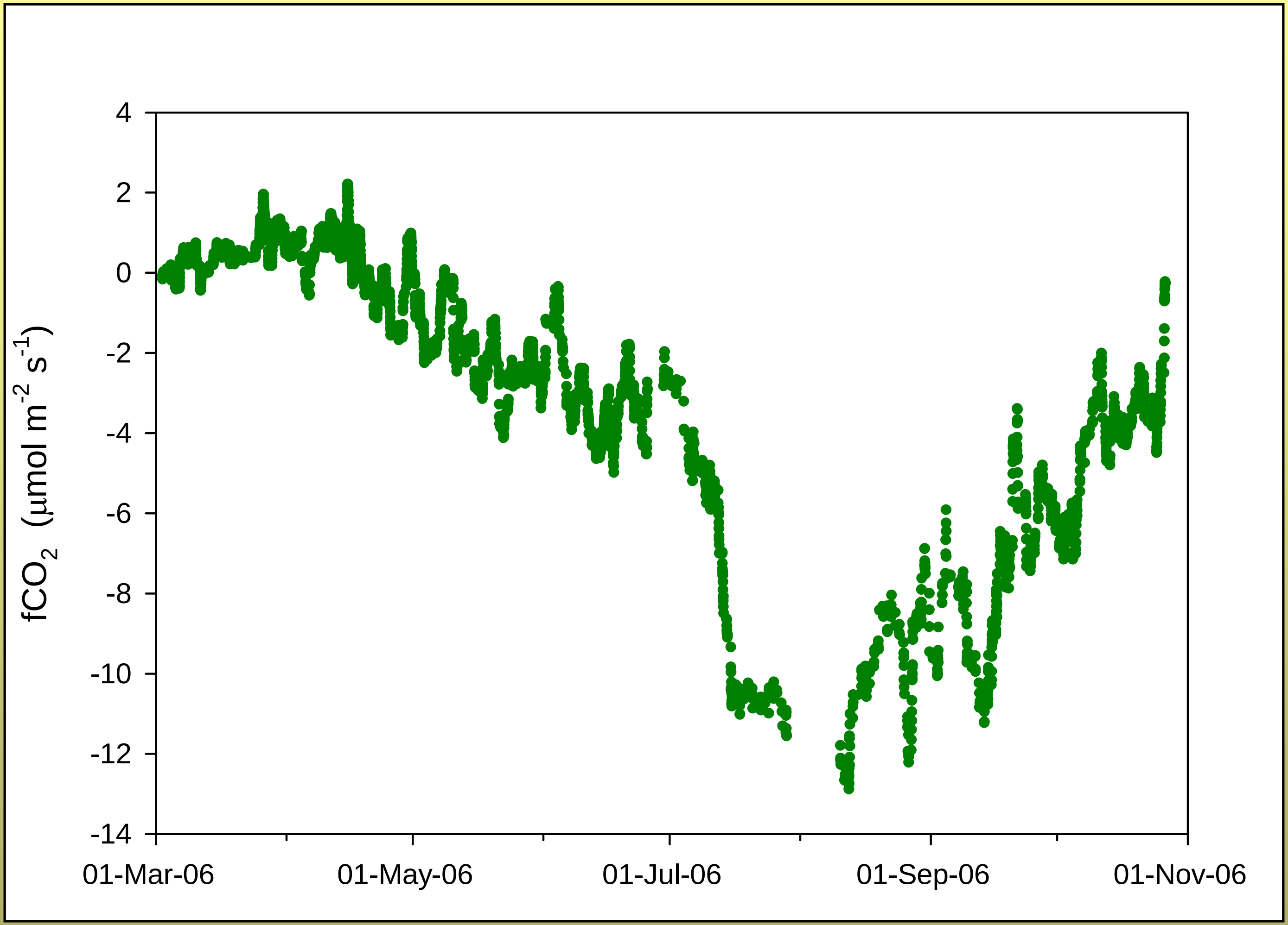


Regional predictions

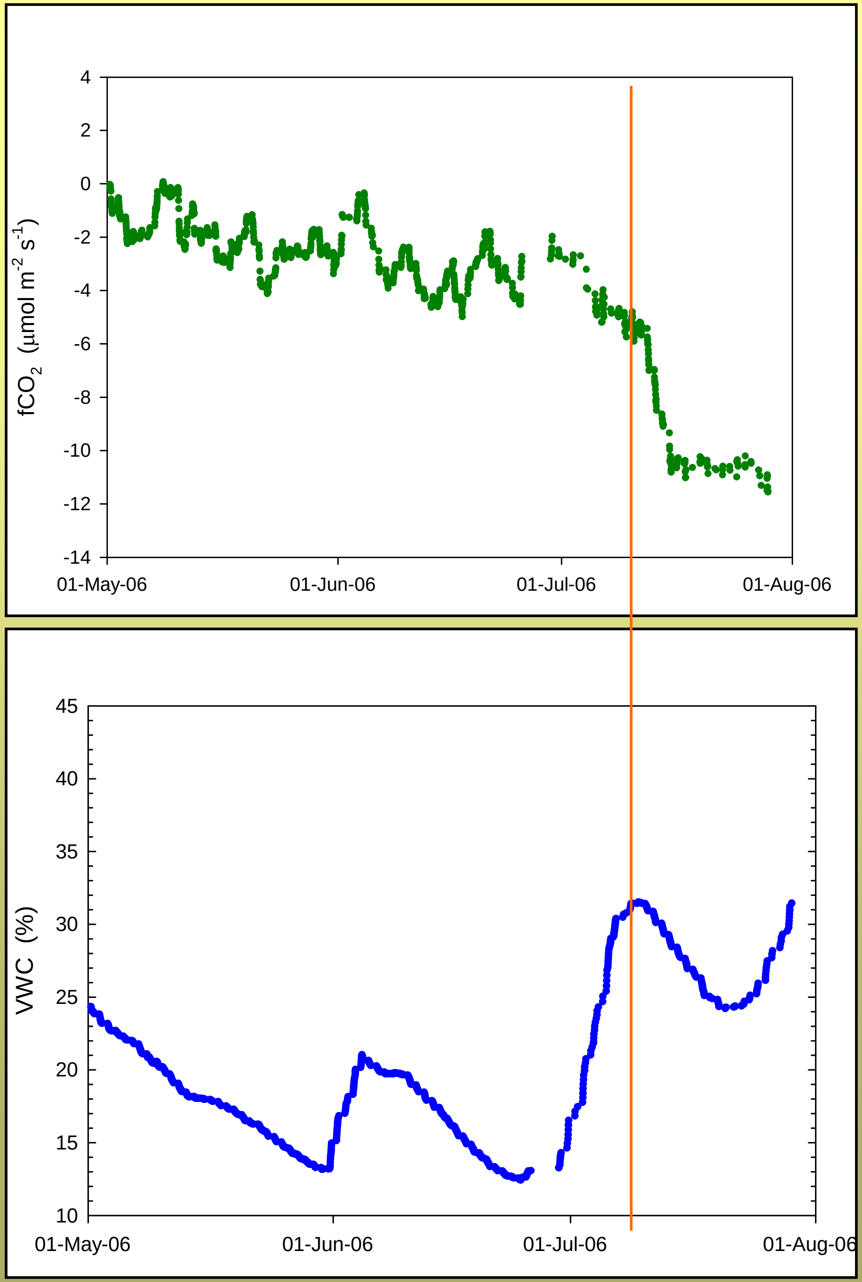


Palmer Drought Severity Index (PDSI). Values less than -3 denote severe drought conditions. Left panels illustrate the 4-year average drought conditions experienced during the 1950s drought and the recent drought. Right panels are future projections of the PDSI based on 42 simulations conducted to support the Fourth Assessment Report of the IPCC. By about 2050, average moisture balance conditions will mimic conditions experienced only rarely at the height of the most severe historical droughts.

Monsoon rain is critical to carbon uptake in the southwest

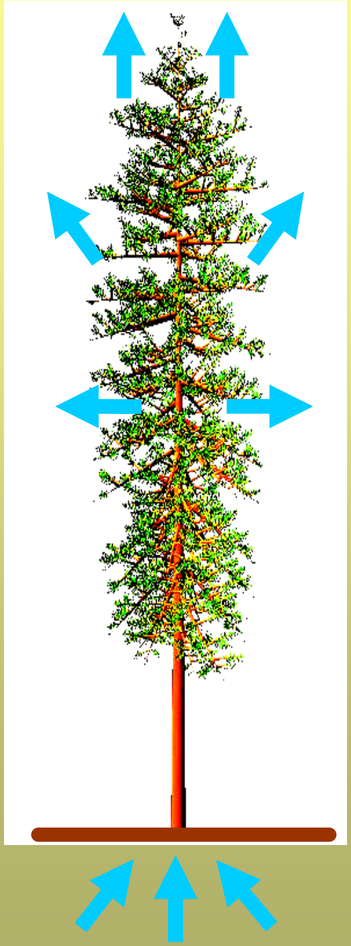


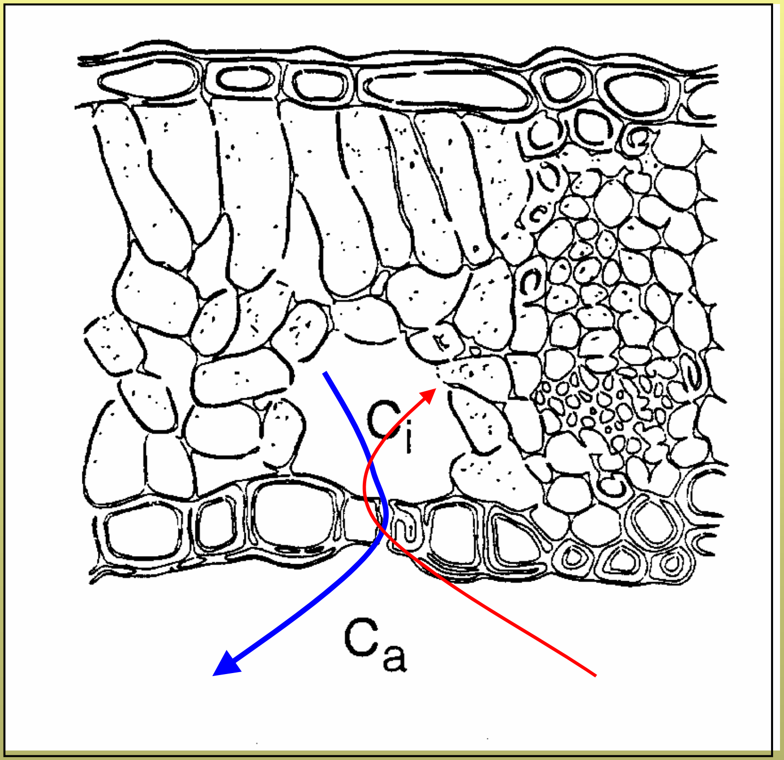
Rahn and McCabe 2006

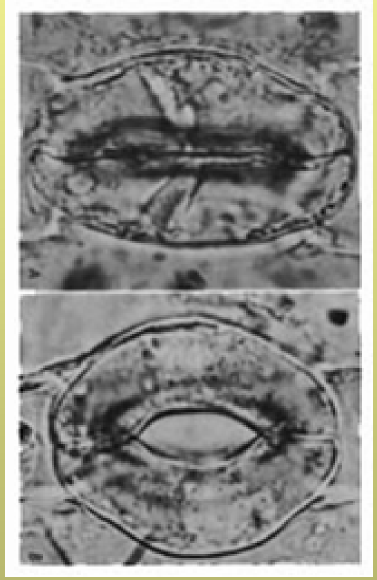


Rahn and McCabe 2006

Stomata: the ecosystem-atmosphere gas exchange interface

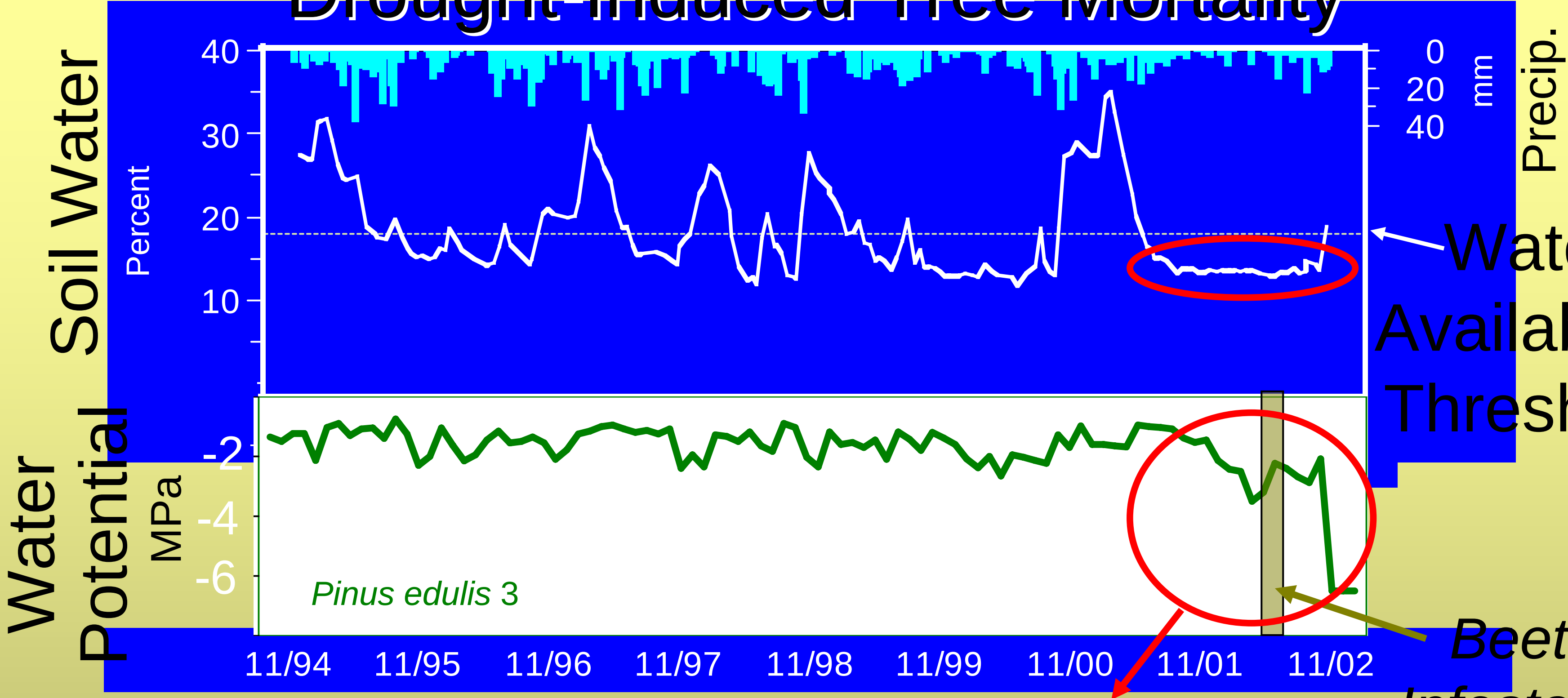






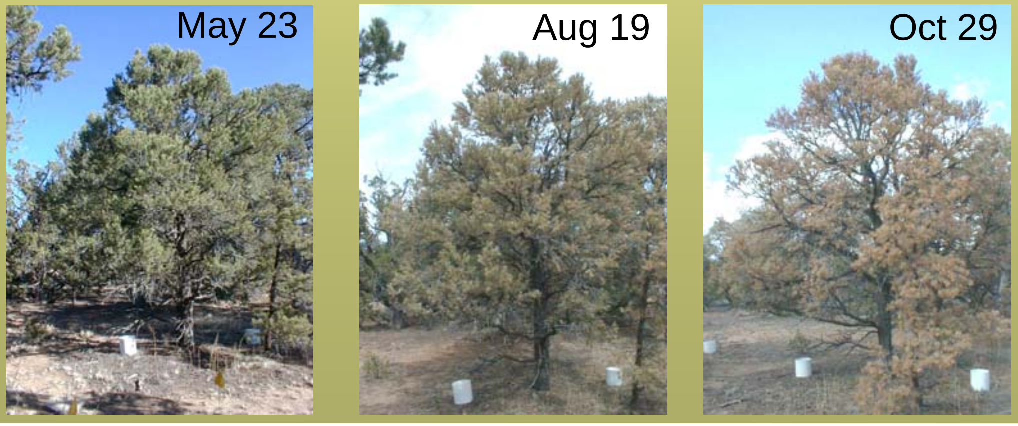
$$\text{Photosynthesis} = \text{conductance}*(C_a\text{-}C_i)$$
$$\text{Transpiration} = \text{conductance}*(E_a\text{-}E_i)$$

Drought-Induced Tree Mortality



Water Availability Threshold

Beetle Infestation Observed



Breshears, Myers & Barnes – *In prep.*

Slide from Craig Allen

Feedbacks?

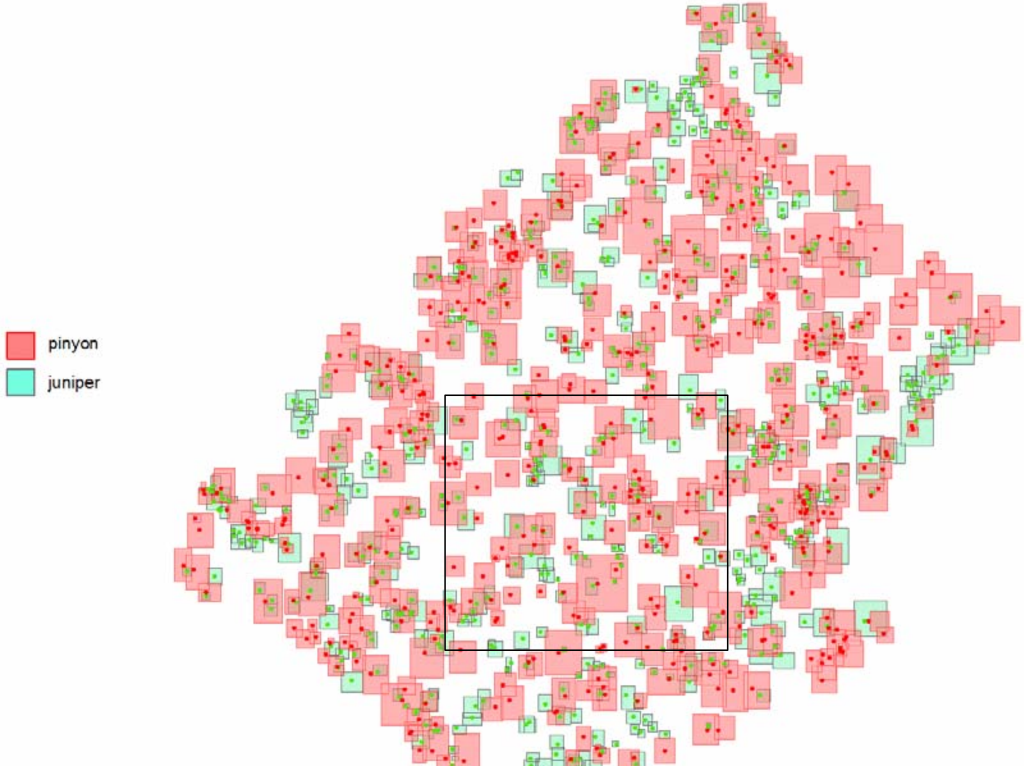
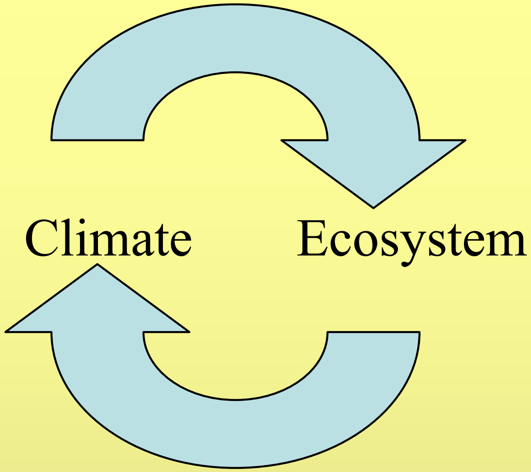
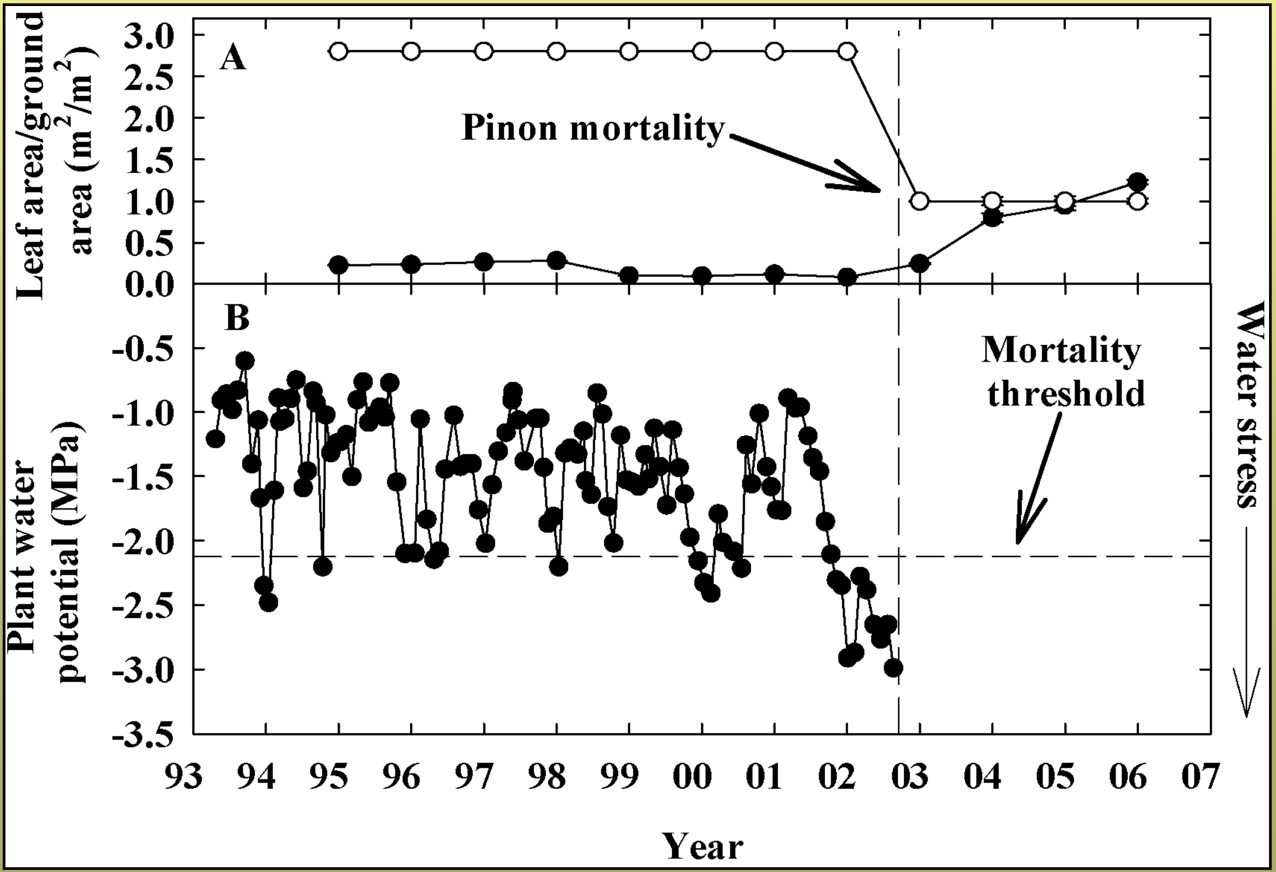


Figure 10. 1600m^2 plot superimposed on a crown-map from *LANL*'s pinon-juniper research area

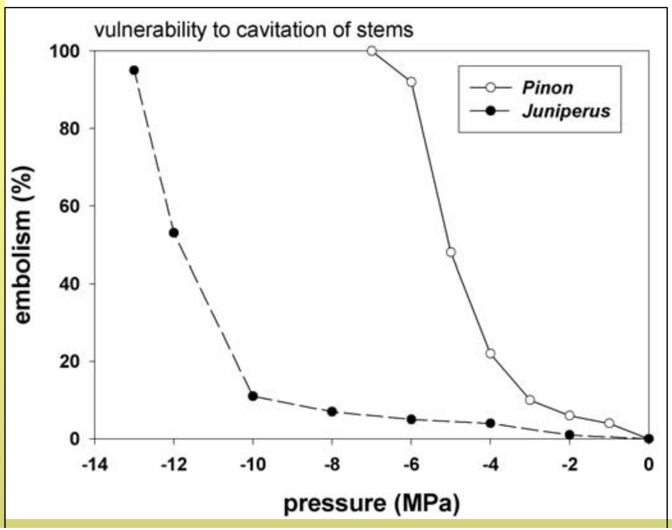


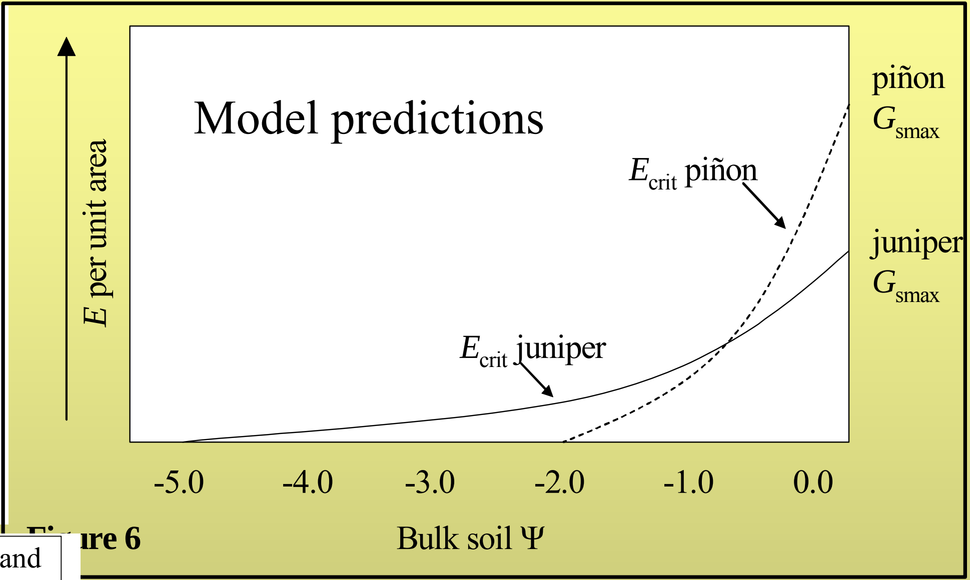
Climate

Ecosystem



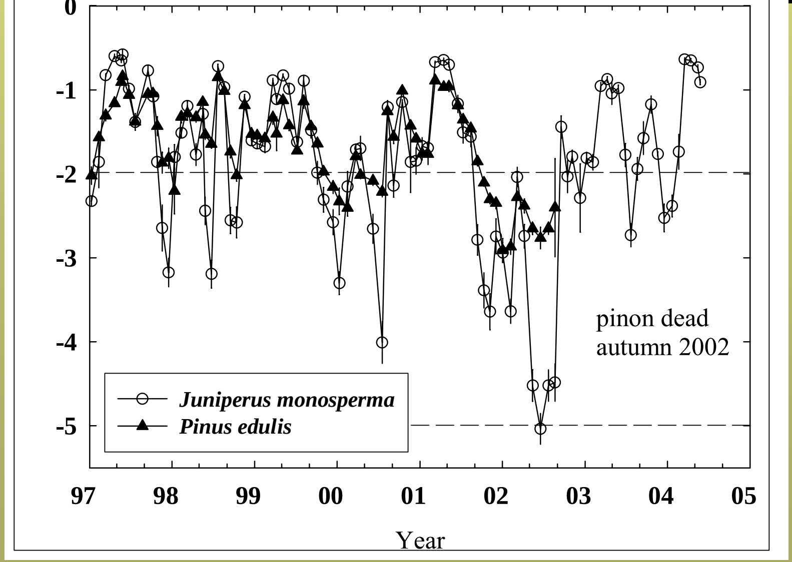
What are the mechanistic causes of mortality, beyond the simple “drought and beetles kill trees”.





Fi ure 6

Figure 7. Seasonal water potential in pinon-juniper woodland



Mutually inclusive hypotheses:

1) runaway embolism

2) prolonged stomatal closure to prevent dehydration results in carbon starvation

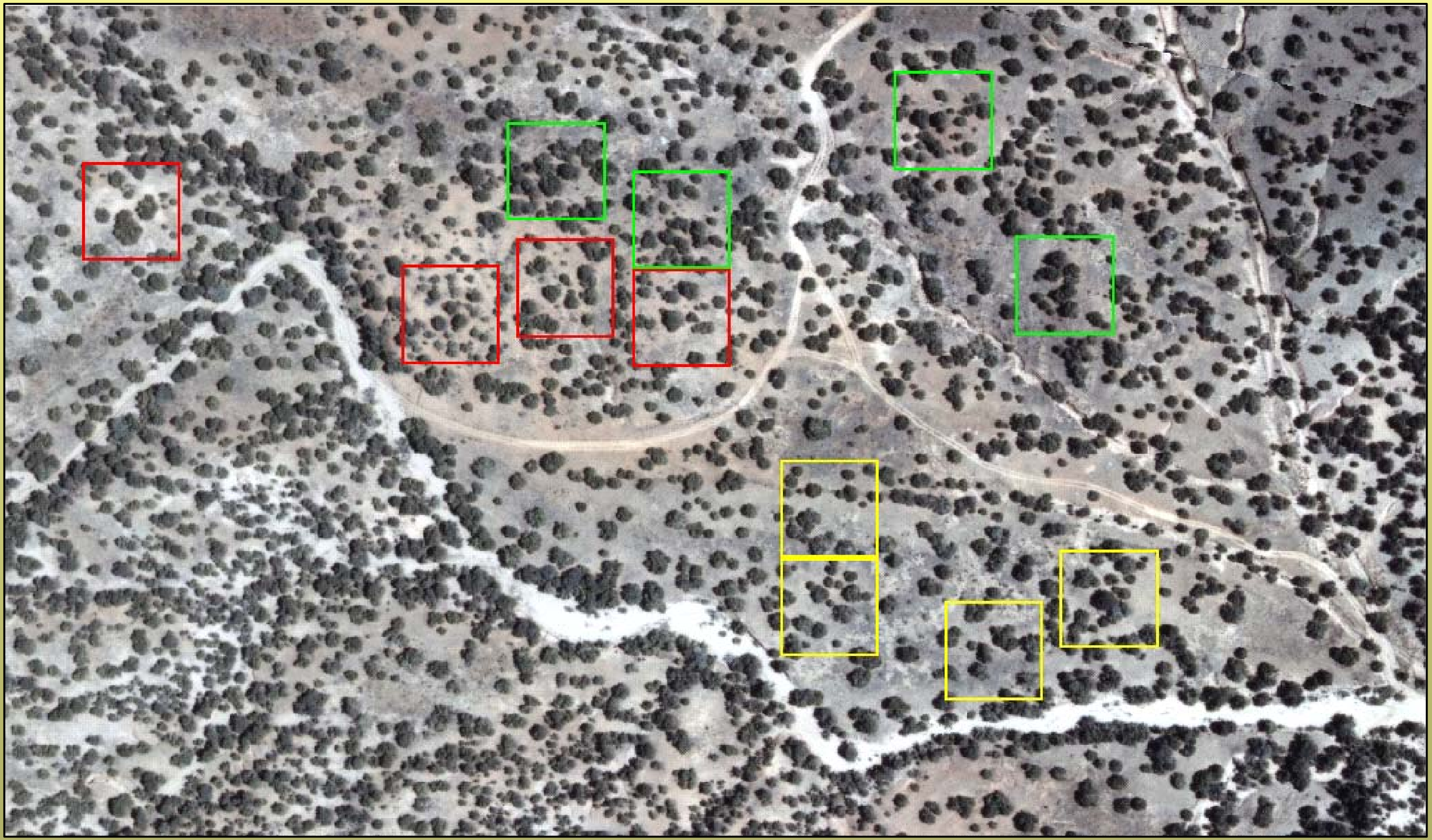
3) prolonged foliar overheating due to lack of transpiration causes enzyme denaturation

4) prolonged carbon starvation results in reduced production of defense compounds

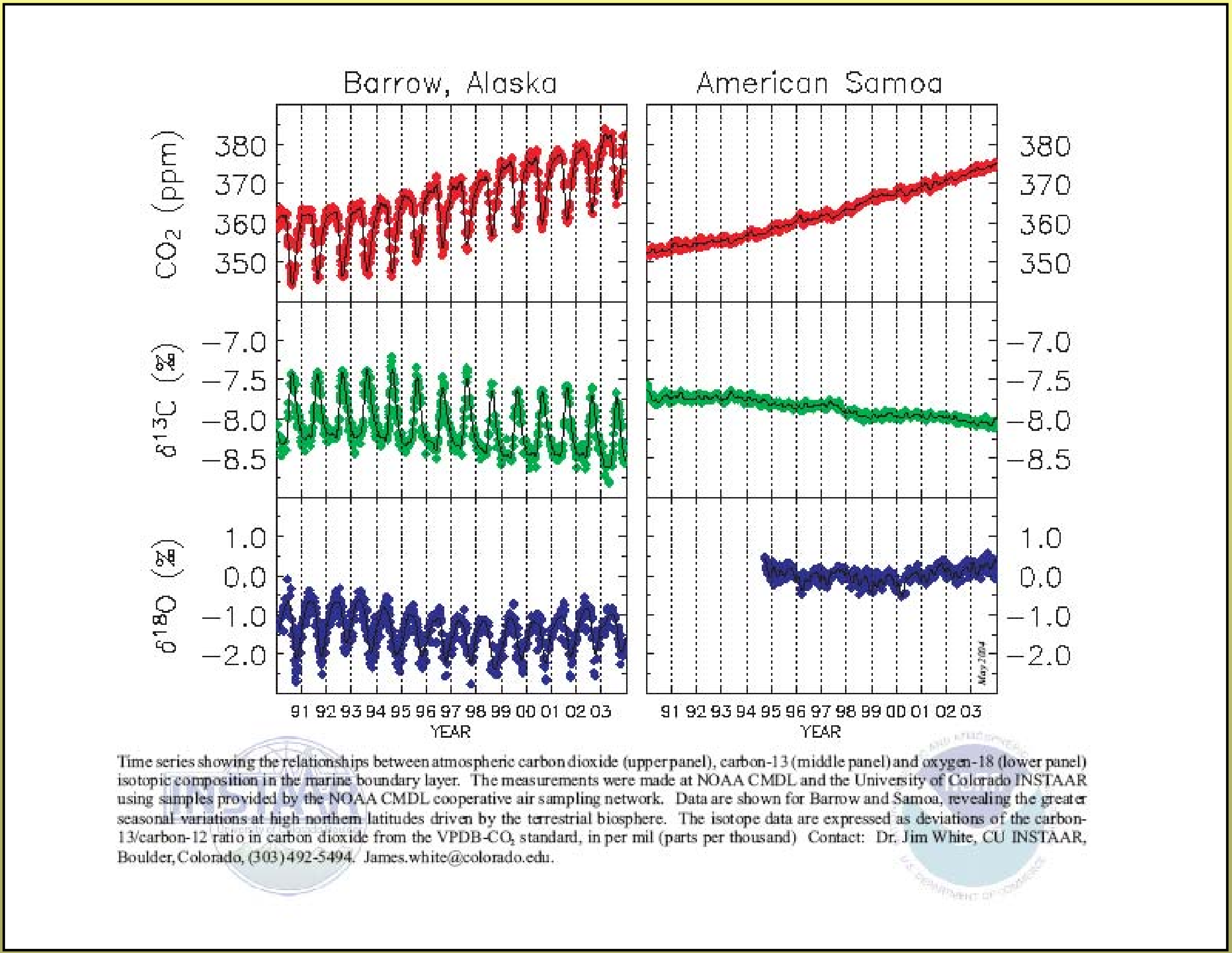
and others…

Prototype rain-out (gutters) and rain-out control (inverted gutters)

Current field site locations
Sevilleta LTER New Mexico



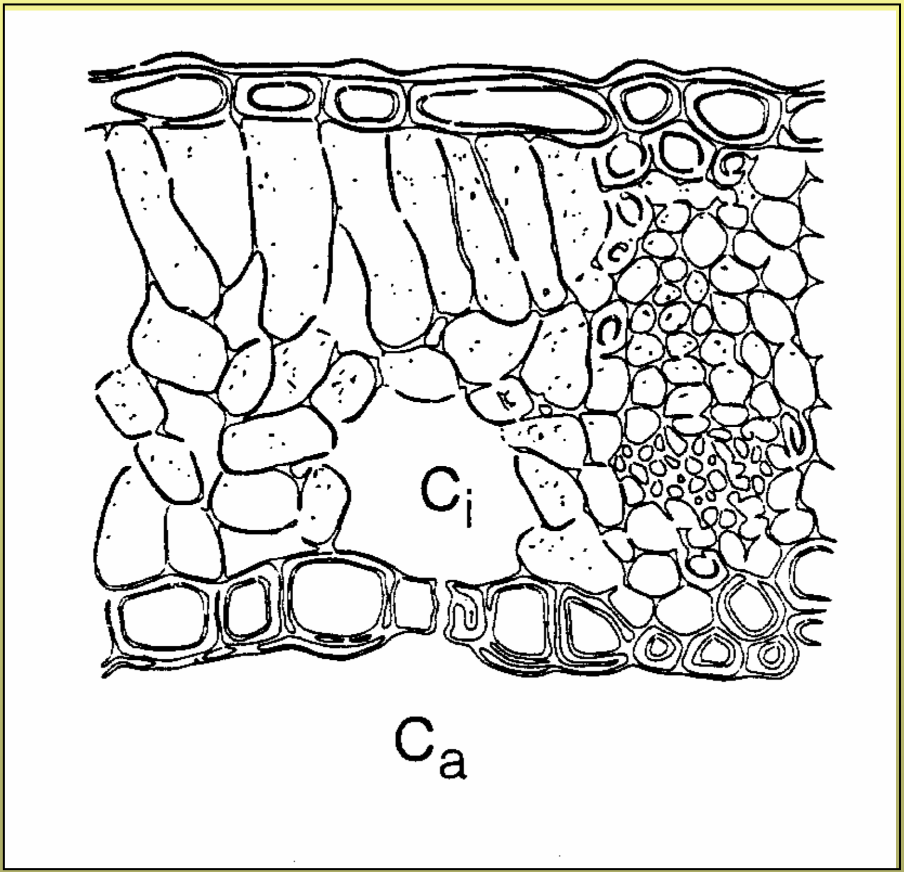
A new tool: stable isotopes of atmospheric CO_2



Time series showing the relationships between atmospheric carbon dioxide (upper panel), carbon-13 (middle panel) and oxygen-18 (lower panel) isotopic composition in the marine boundary layer. The measurements were made at NOAA CMDL and the University of Colorado INSTAAR using samples provided by the NOAA CMDL cooperative air sampling network. Data are shown for Barrow and Samoa, revealing the greater seasonal variations at high northern latitudes driven by the terrestrial biosphere. The isotope data are expressed as deviations of the carbon-13/carbon-12 ratio in carbon dioxide from the VPDB-CO_2 standard, in per mil (parts per thousand) Contact: Dr. Jim White, CU INSTAAR, Boulder, Colorado, (303) 492-5494. James.white@colorado.edu.

Stable carbon isotope ratios

$\delta^{13}C \approx C_i/C_a$

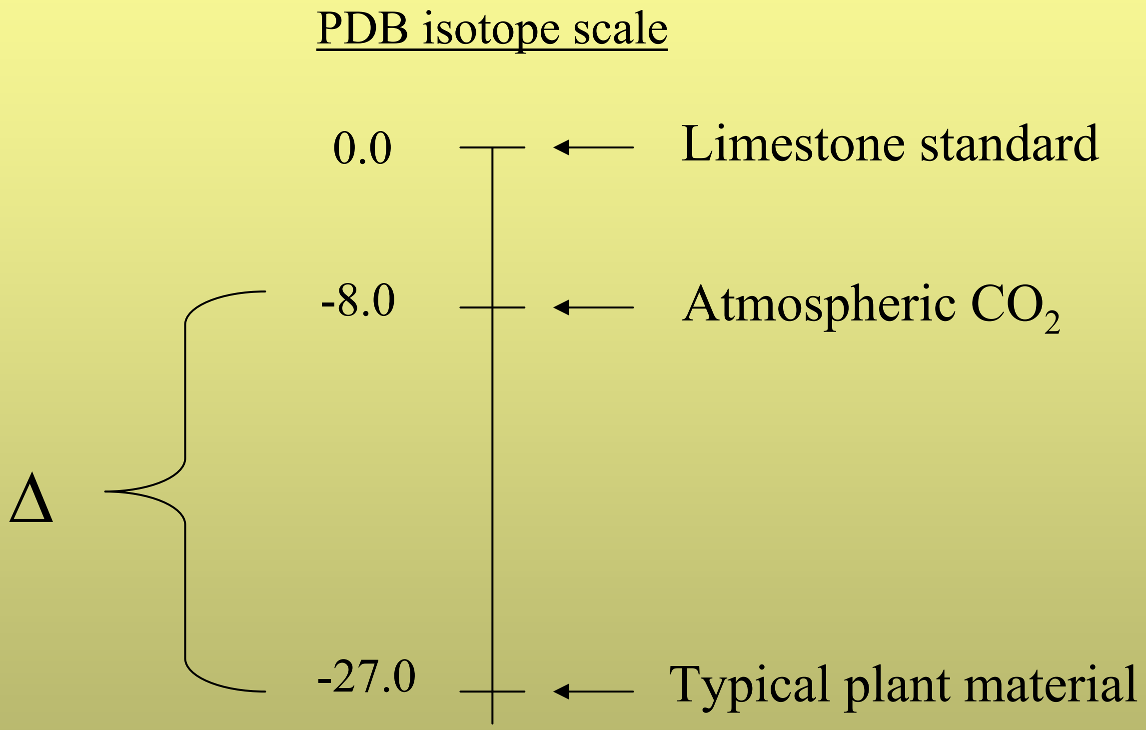


^{12}C ~ 99% of atmospheric CO_2

^{13}C ~ 1% of atmospheric CO_2 (1 extra neutron)

$\delta^{13}C \approx (-)C_i/C_a$

$\delta^{13}C$ of biological materials is regulated by carbon isotope discrimination (Δ)



PDB isotope scale

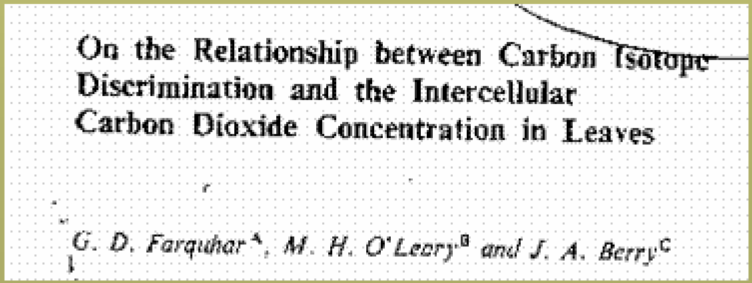
0.0 ← Limestone standard

-8.0 ← Atmospheric CO_2

Δ

-27.0 ← Typical plant material

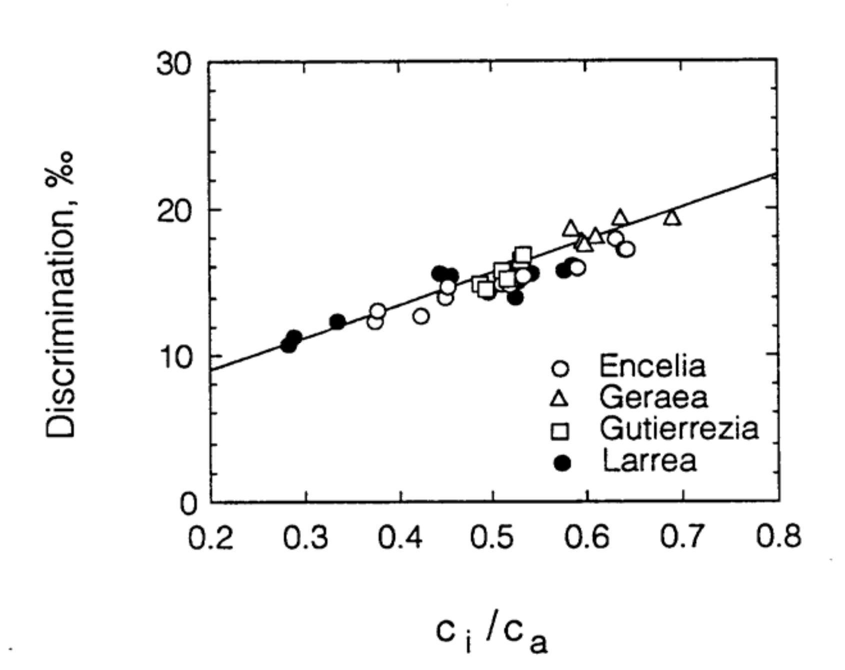
The classic, first text

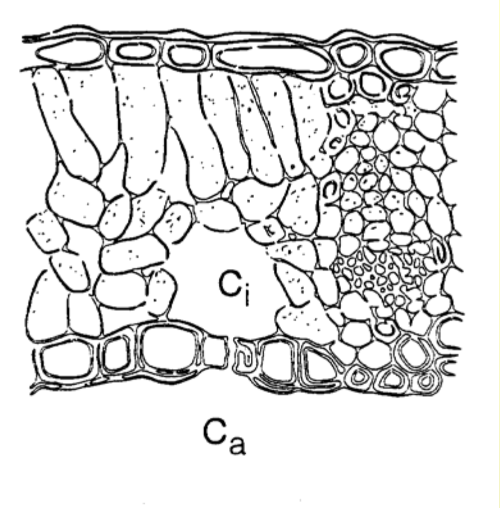


On the Relationship between Carbon Isotope Discrimination and the Intercellular Carbon Dioxide Concentration in Leaves

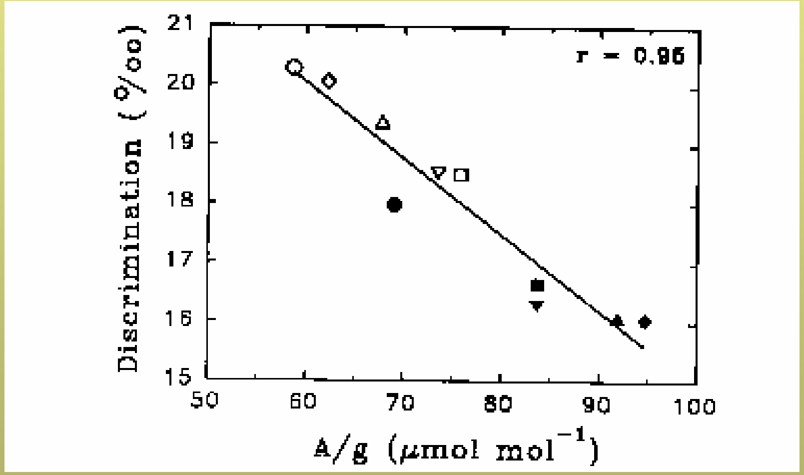
G. D. Farquhar[A], M. H. O'Leary[B] and J. A. Berry[C]

Ehleringer et al. 1992





Meinzer et al. 1993



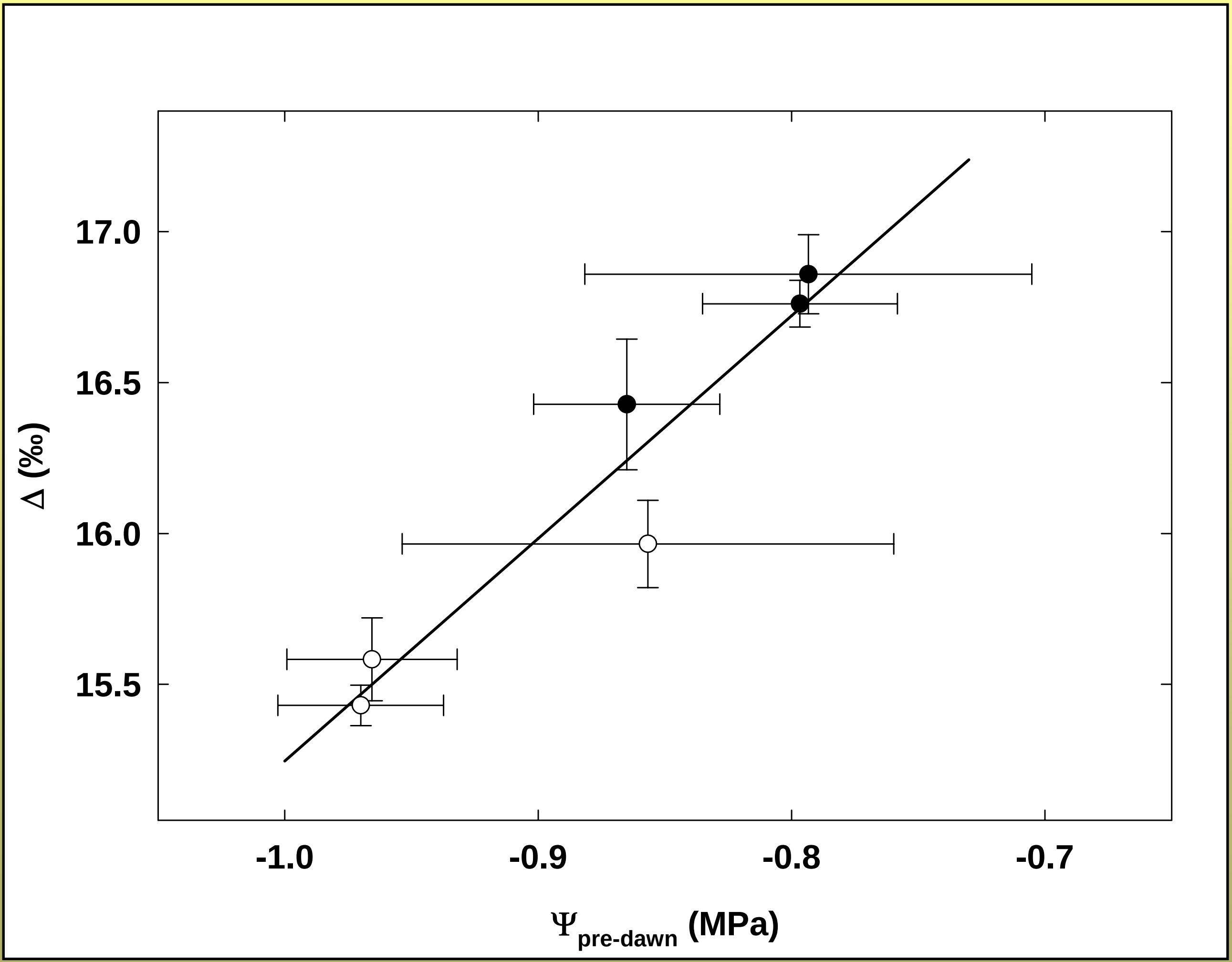
$$\Delta = a + (b-a)C_i/C_a$$

$$\Delta = [\delta^{13}C_a - \delta^{13}C_p] / [1 + (\delta^{13}C_p/1000)]$$

Wet soil
High Ci/Ca

Dry soil
Low Ci/Ca

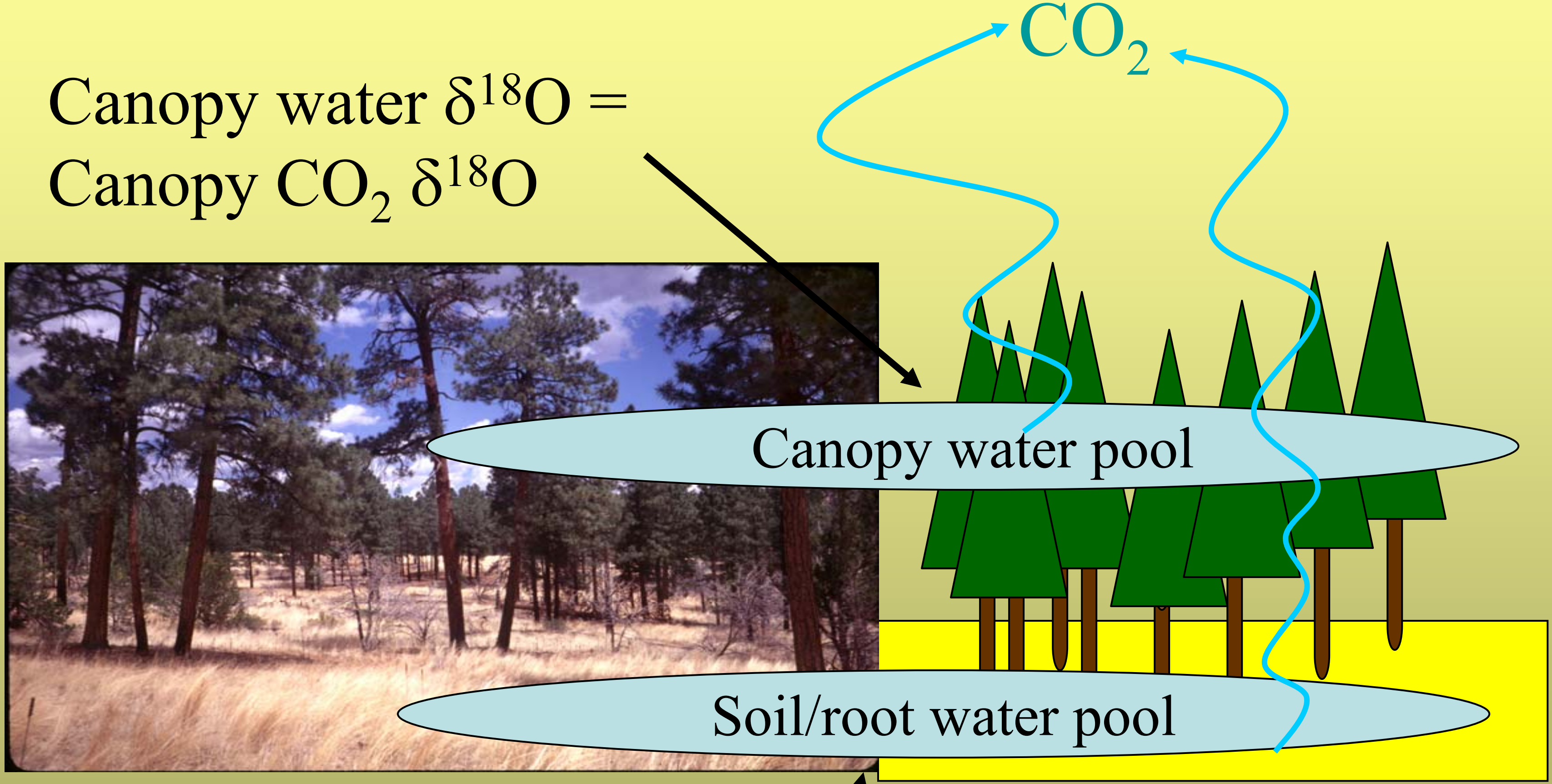
Δ is linked to soil water availability



McDowell et al. *Plant, Cell and Environment,* 2003

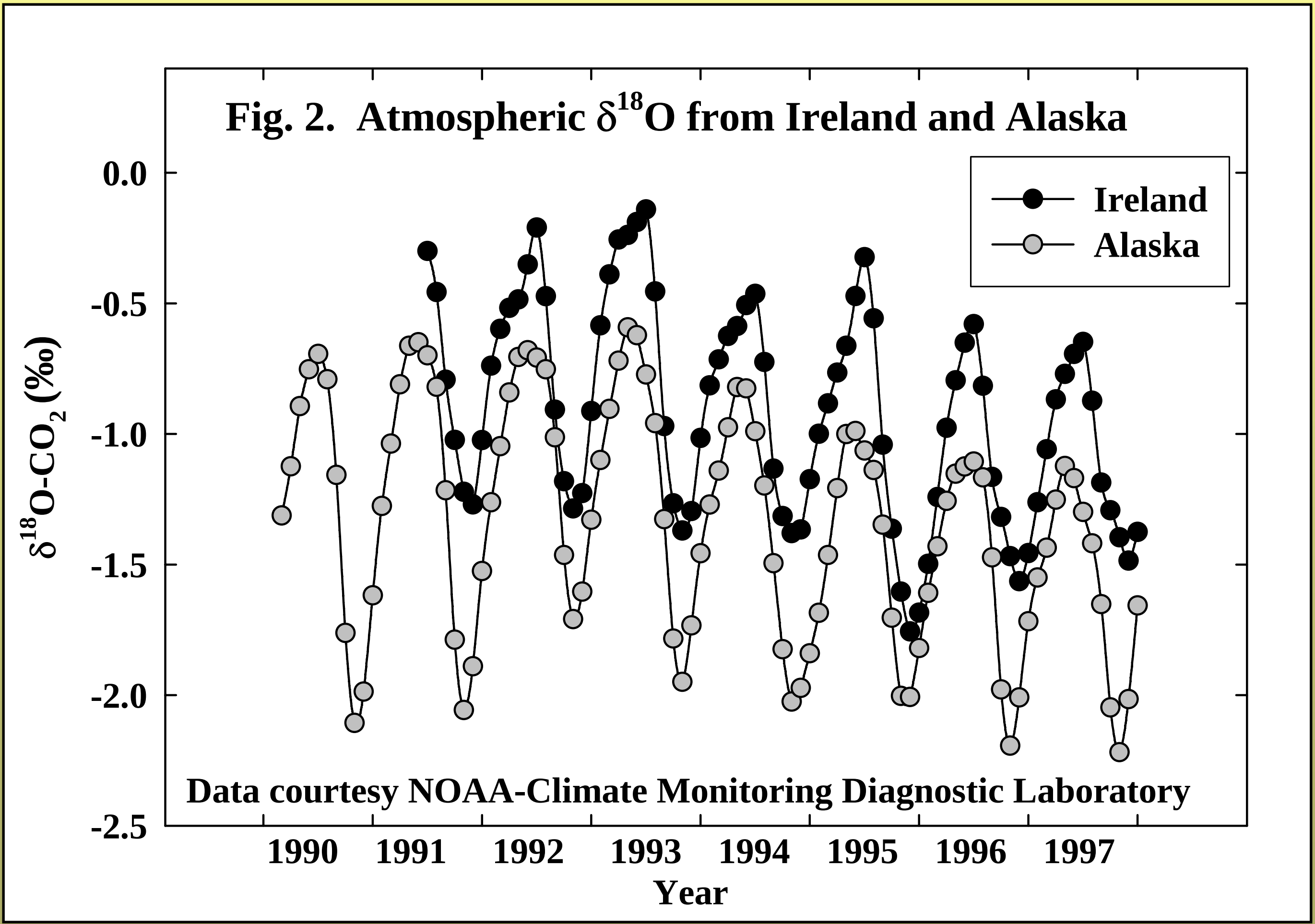
CO_2 takes the $\delta^{18}O$ signature of water it passes through

Canopy water $\delta^{18}O$ =
Canopy CO_2 $\delta^{18}O$

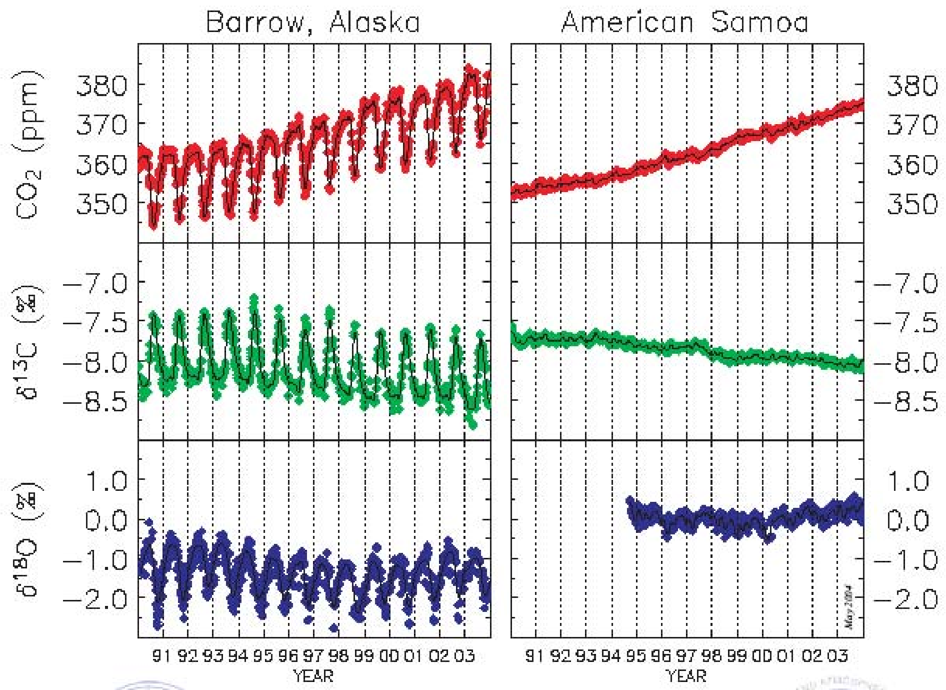


Soil/root water $\delta^{18}O$ = soil/root CO_2 $\delta^{18}O$

Oxygen isotopes trace regional water cycle

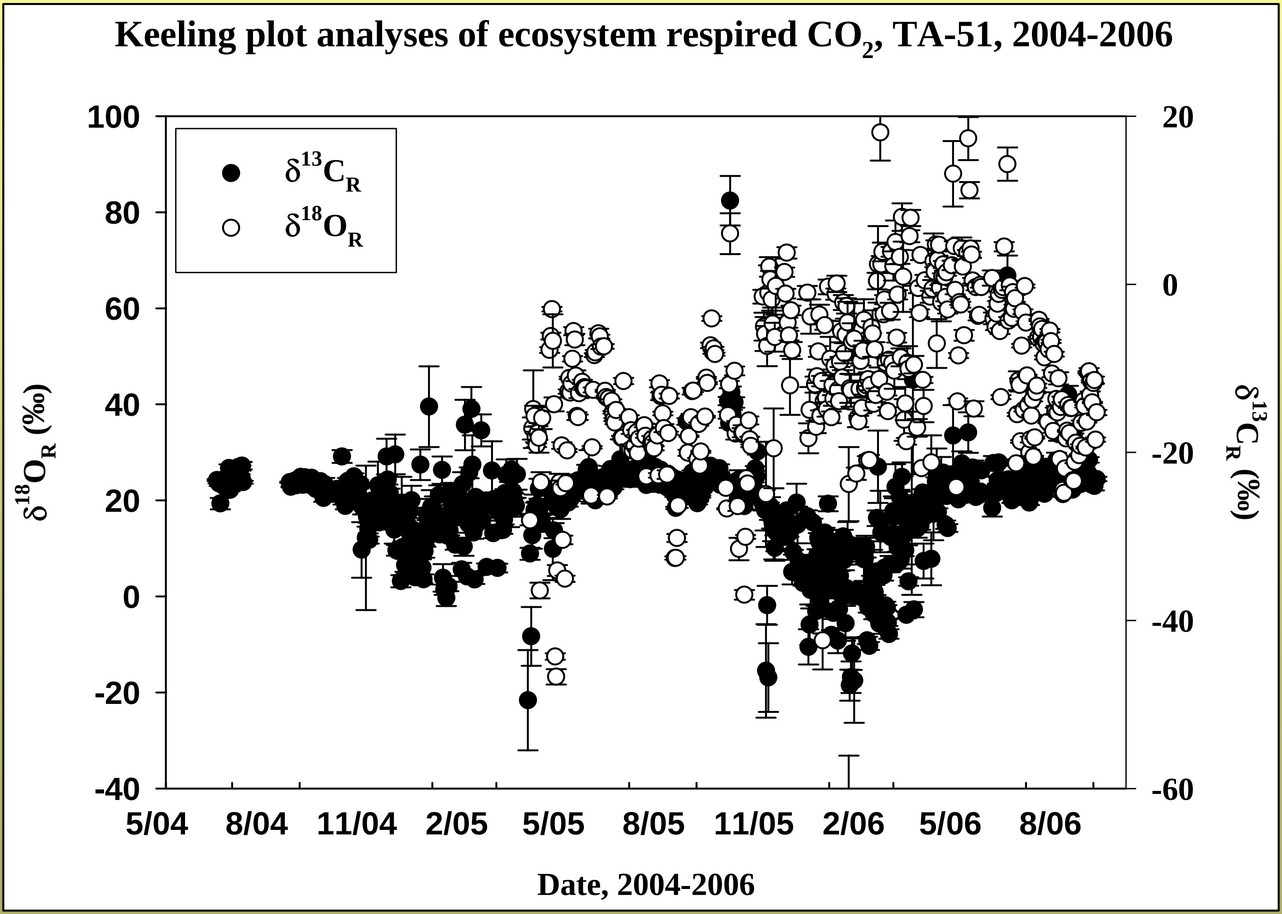


$\delta^{13}C$ and $\delta^{18}O$ allow mechanistic interpretation of CO_2 patterns



Time series showing the relationships between atmospheric carbon dioxide (upper panel), carbon-13 (middle panel) and oxygen-18 (lower panel) isotopic composition in the marine boundary layer. The measurements were made at NOAA CMDL and the University of Colorado INSTAAR using samples provided by the NOAA CMDL cooperative air sampling network. Data are shown for Barrow and Samoa, revealing the greater seasonal variations at high northern latitudes driven by the terrestrial biosphere. The isotope data are expressed as deviations of the carbon-13/carbon-12 ratio in carbon dioxide from the VPDB-CO_2 standard, in per mil (parts per thousand) Contact: Dr. Jim White, CU INSTAAR, Boulder, Colorado, (303) 492-5494. James.white@colorado.edu.

Ecosystem-scale $\delta^{13}C$ and $\delta^{18}O$



δ^{13}C records water availability

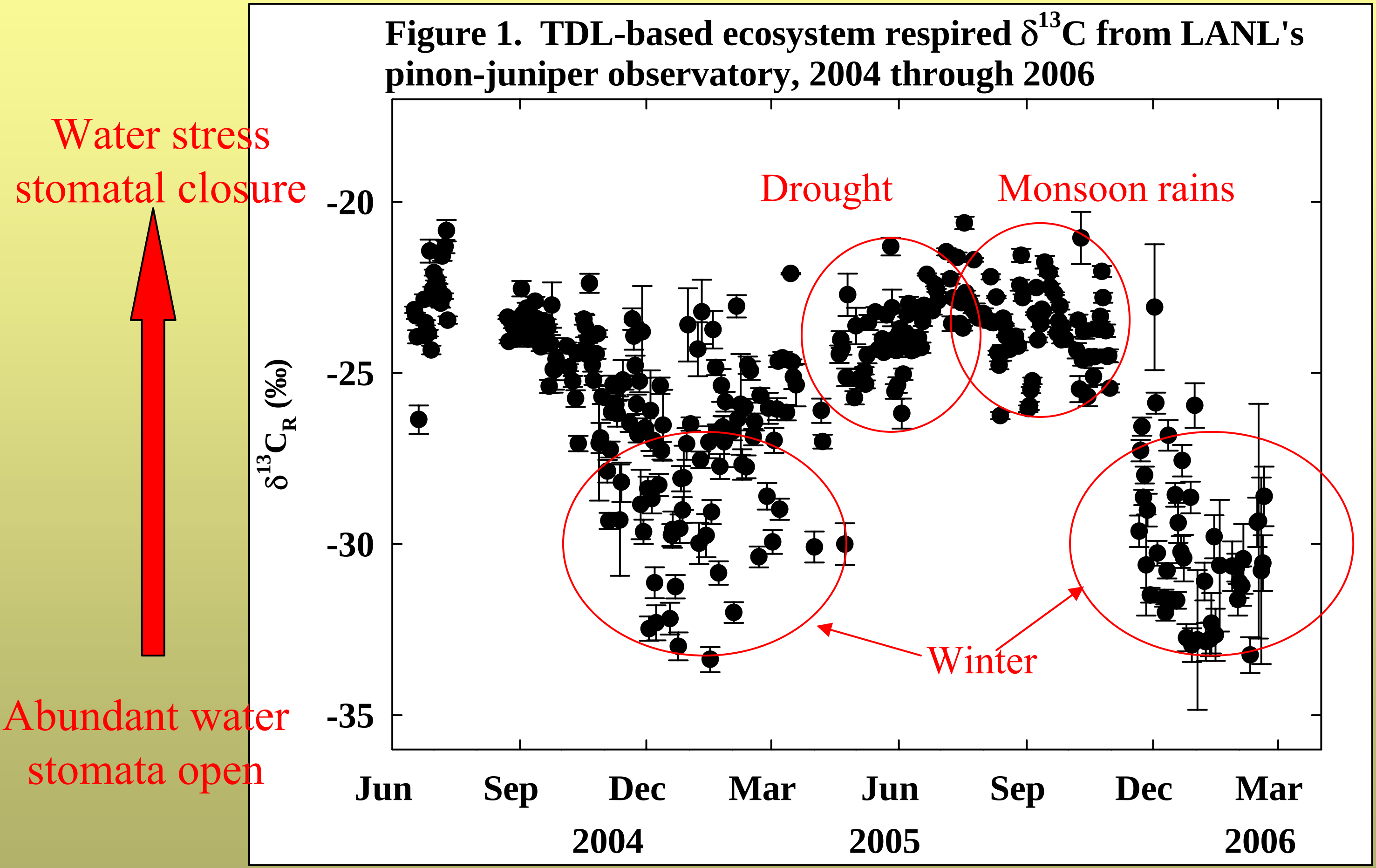


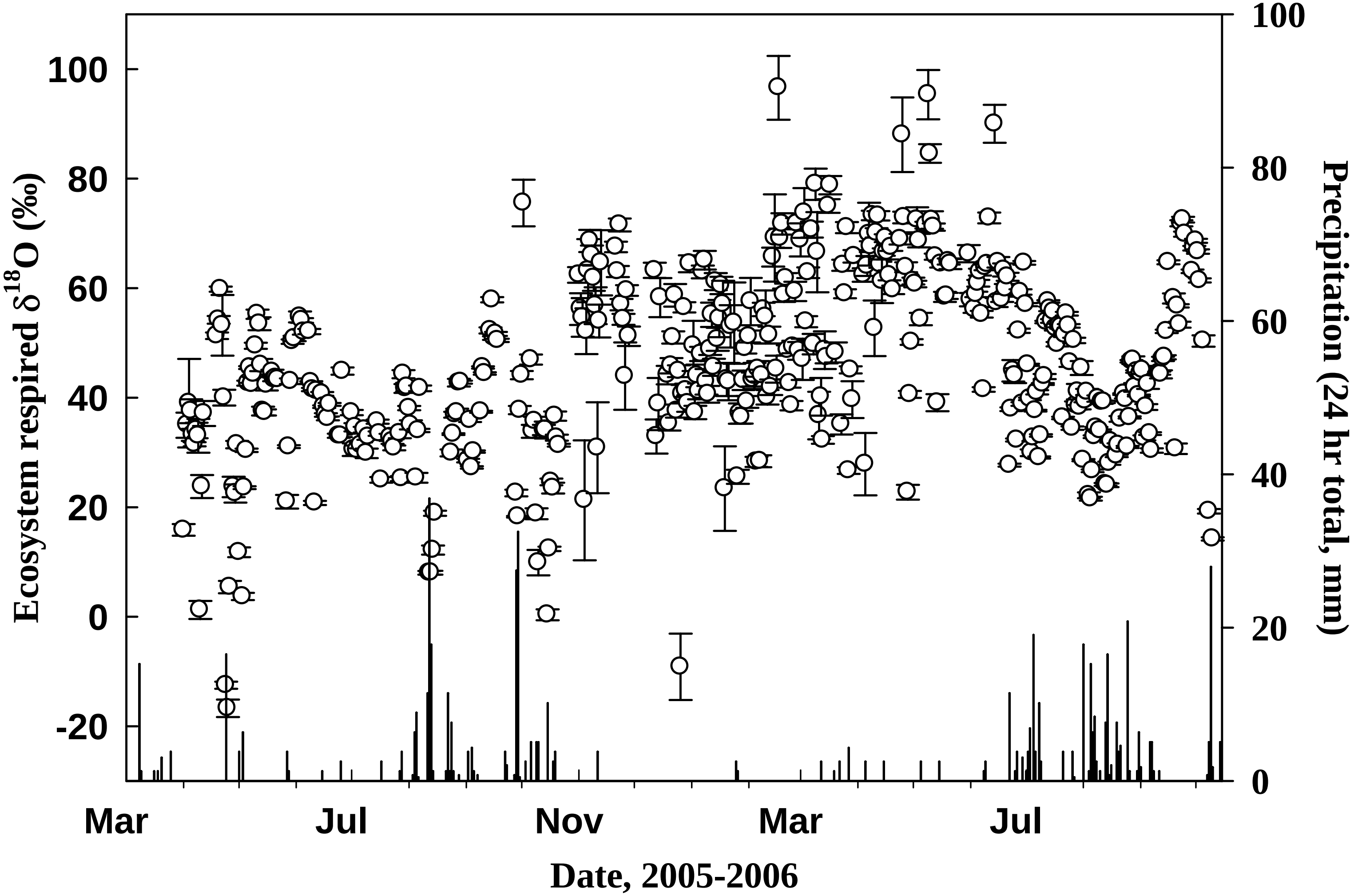
Figure 1. TDL-based ecosystem respired δ^{13}C from LANL's pinon-juniper observatory, 2004 through 2006

Water stress
stomatal closure

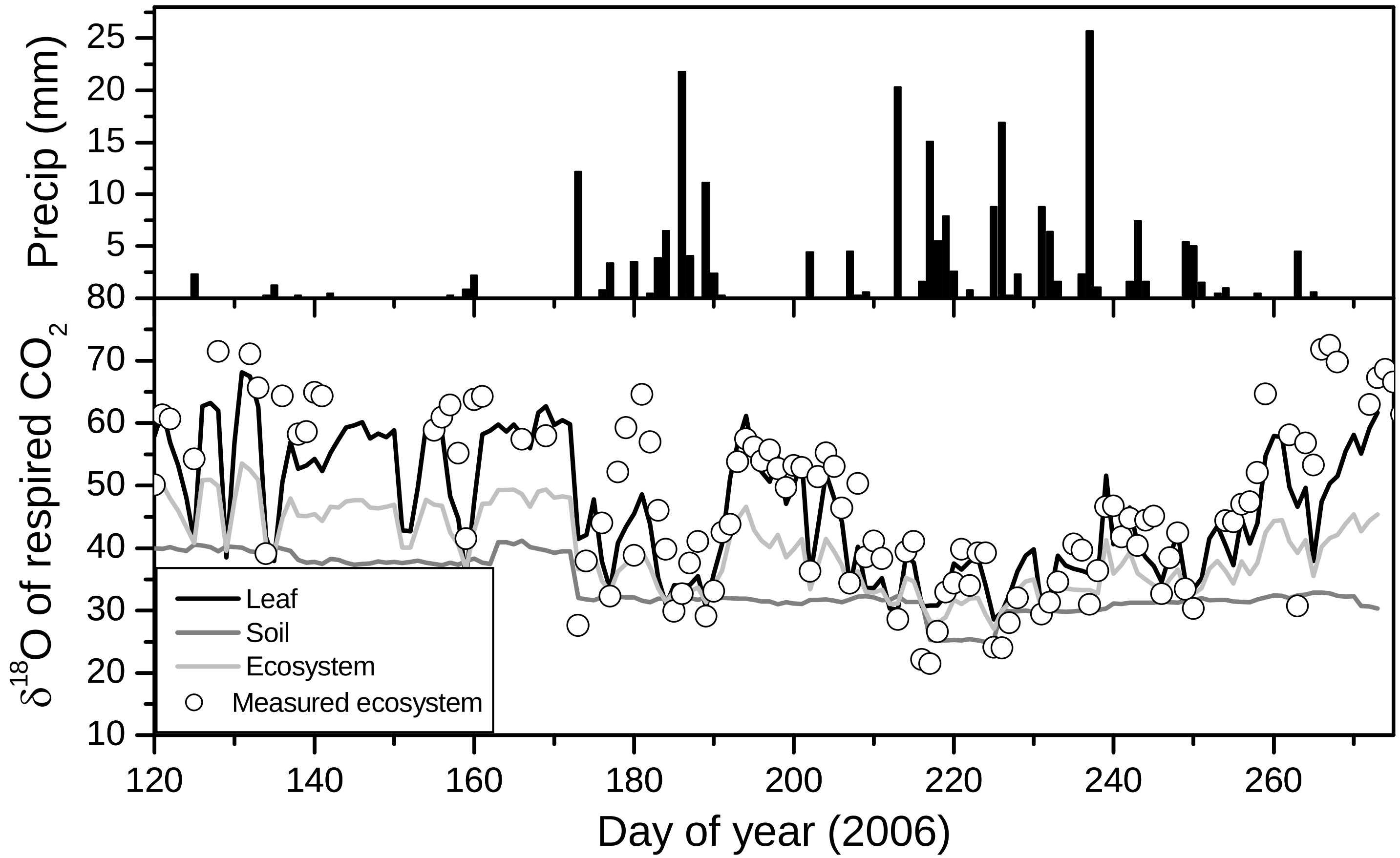
Abundant water
stomata open

δ^{18}O records water sources

Figure 3. δ^{18}O of ecosystem respired CO_2 at *LANL*'s PJ woodland



Models that may be used to infer water and carbon cycles can be driven using CO_2 isotopes



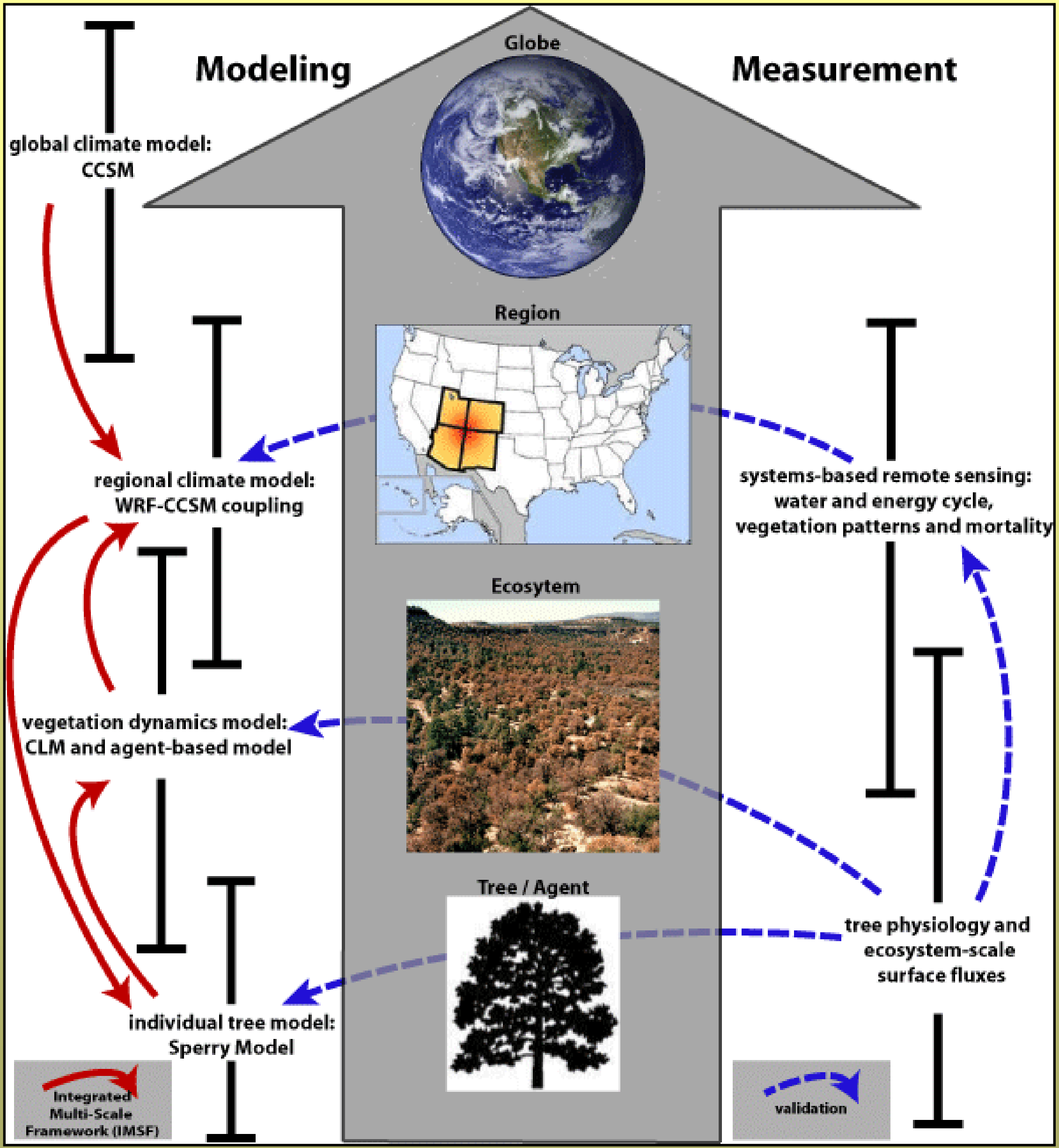
IGPP workshop, March 2007

Future path forward: key issues

- Understand and model regional climate/ecosystem interactions
- Understand and model vegetation mortality
- Understand and validate isotope applications for “early warning” applications towards regional and global environmental impacts

A path forward

Integrating
measurements
models
remote sensing



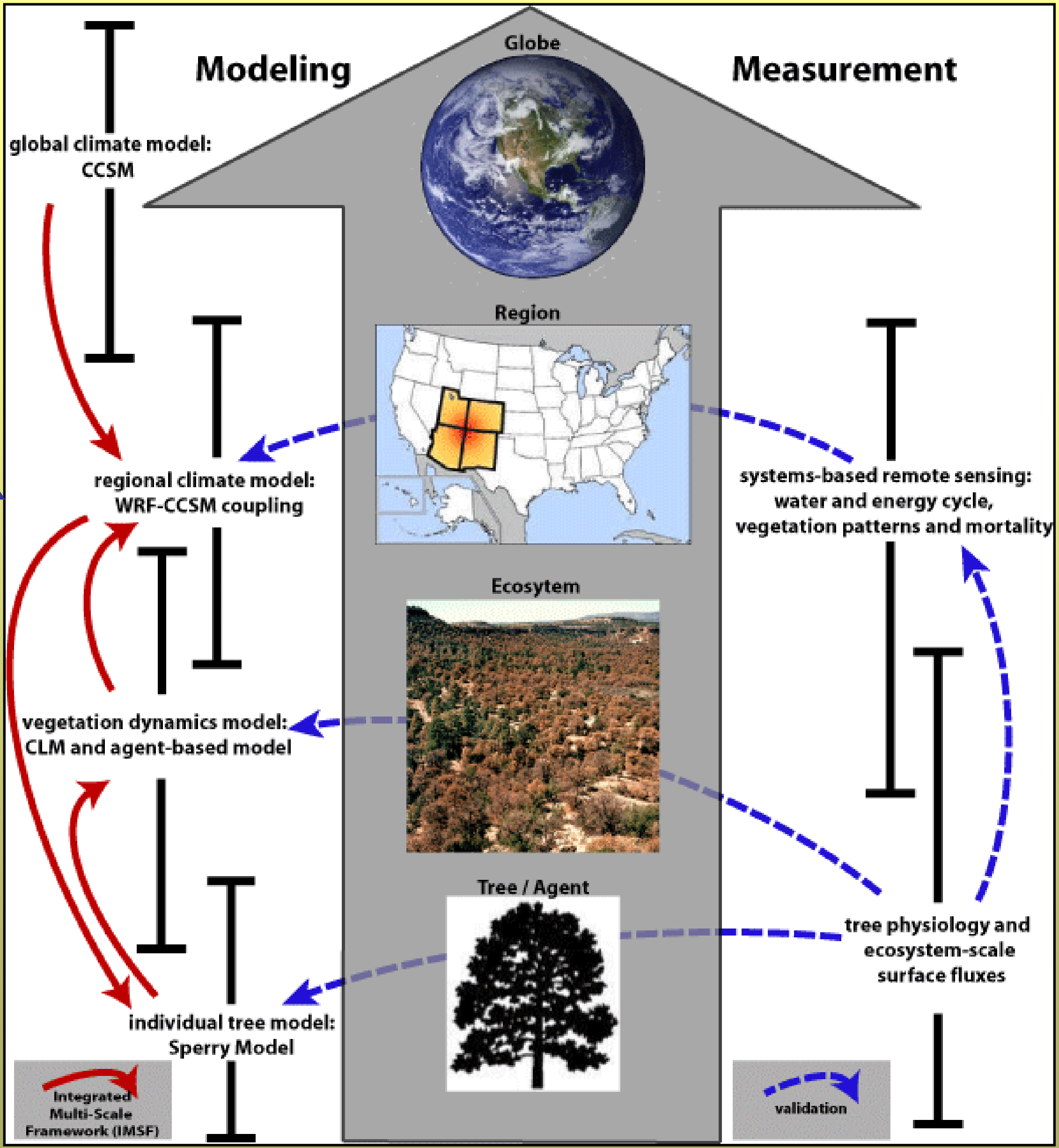
A path forward

Integrating isotopes

δ

δ

δ



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