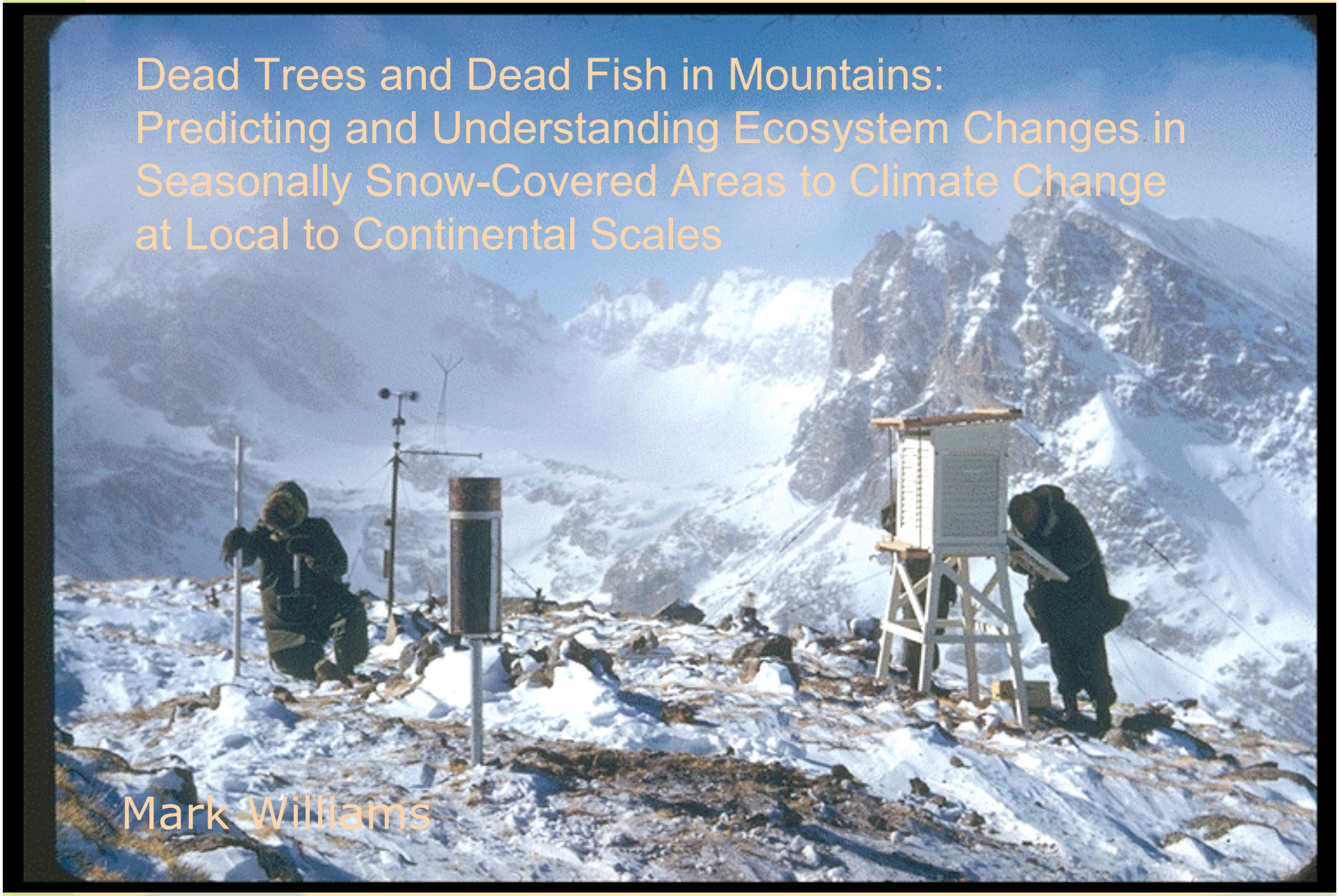
Dead Trees and Dead Fish in Mountains: Predicting and Understanding Ecosystem Changes in Seasonally Snow-Covered Areas to Climate Change at Local to Continental Scales



Mark Williams

Climate Change and Carbon Cycling in Western Forests

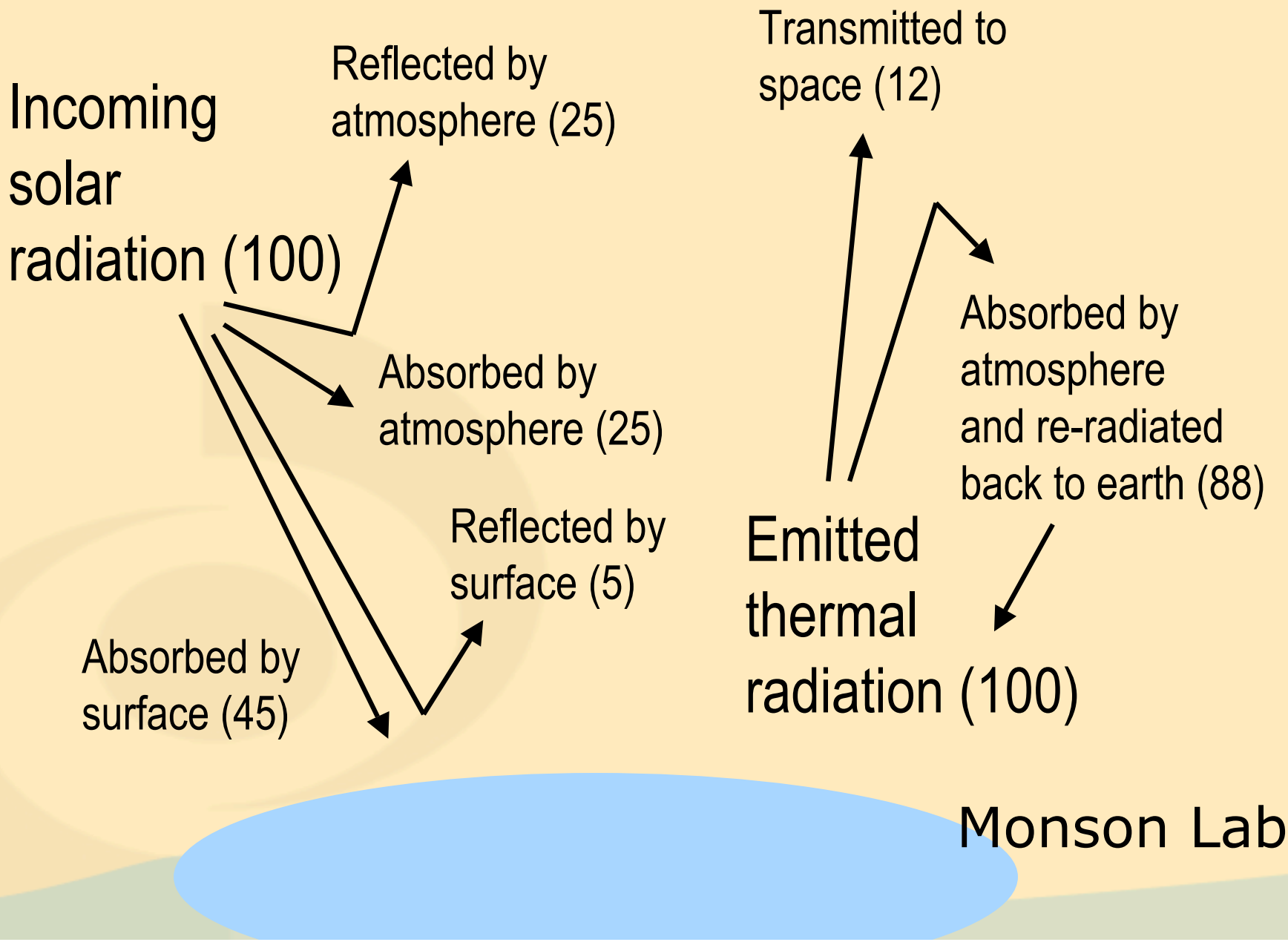
- All coupled land-atmosphere models predict that a longer growing season means more forest growth, greater NEE and NPP.

- Are these results appropriate for high-elevation forests of the western US?

Monson Lab

"I drove to the garden centre for a tree to offset my carbon footprint...
so now I've got to go back for another one..."

Simplified Global Radiation Energy Balance



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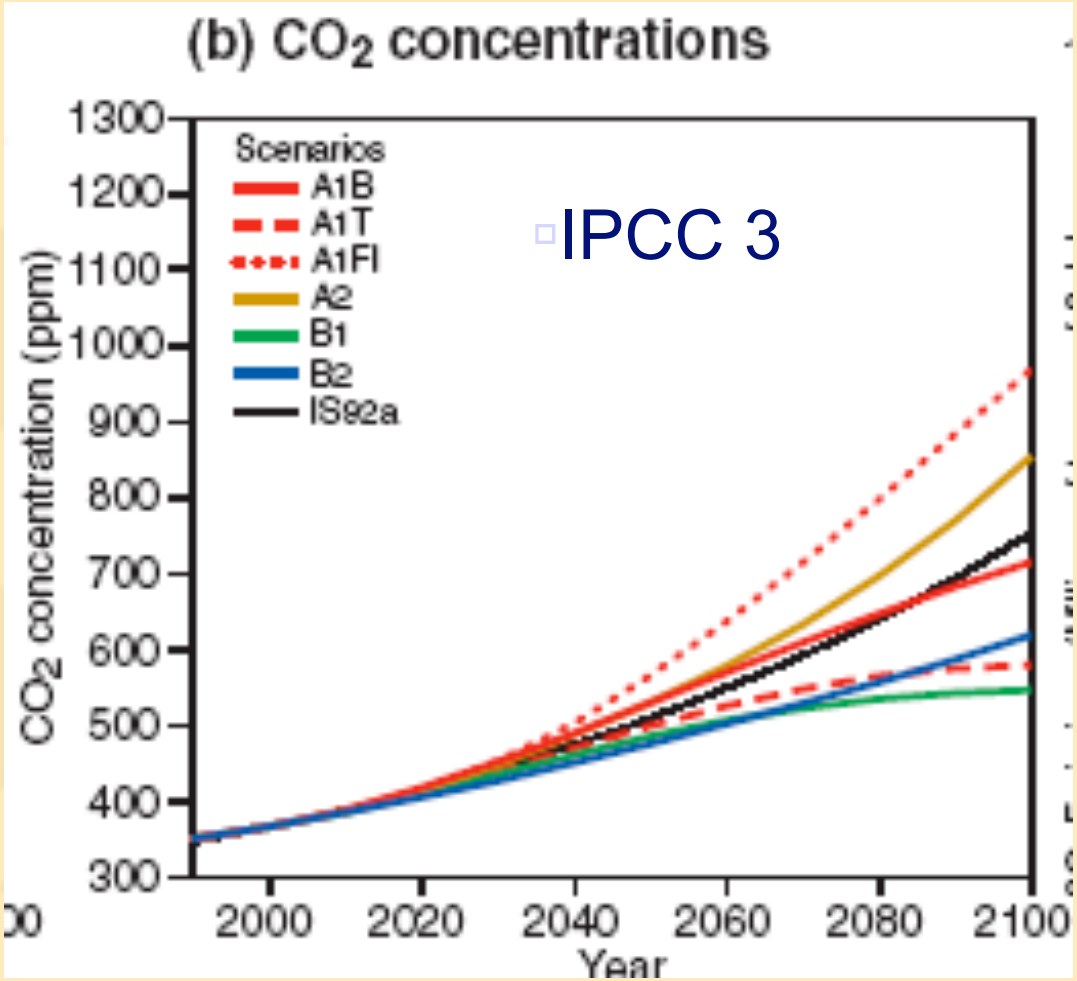
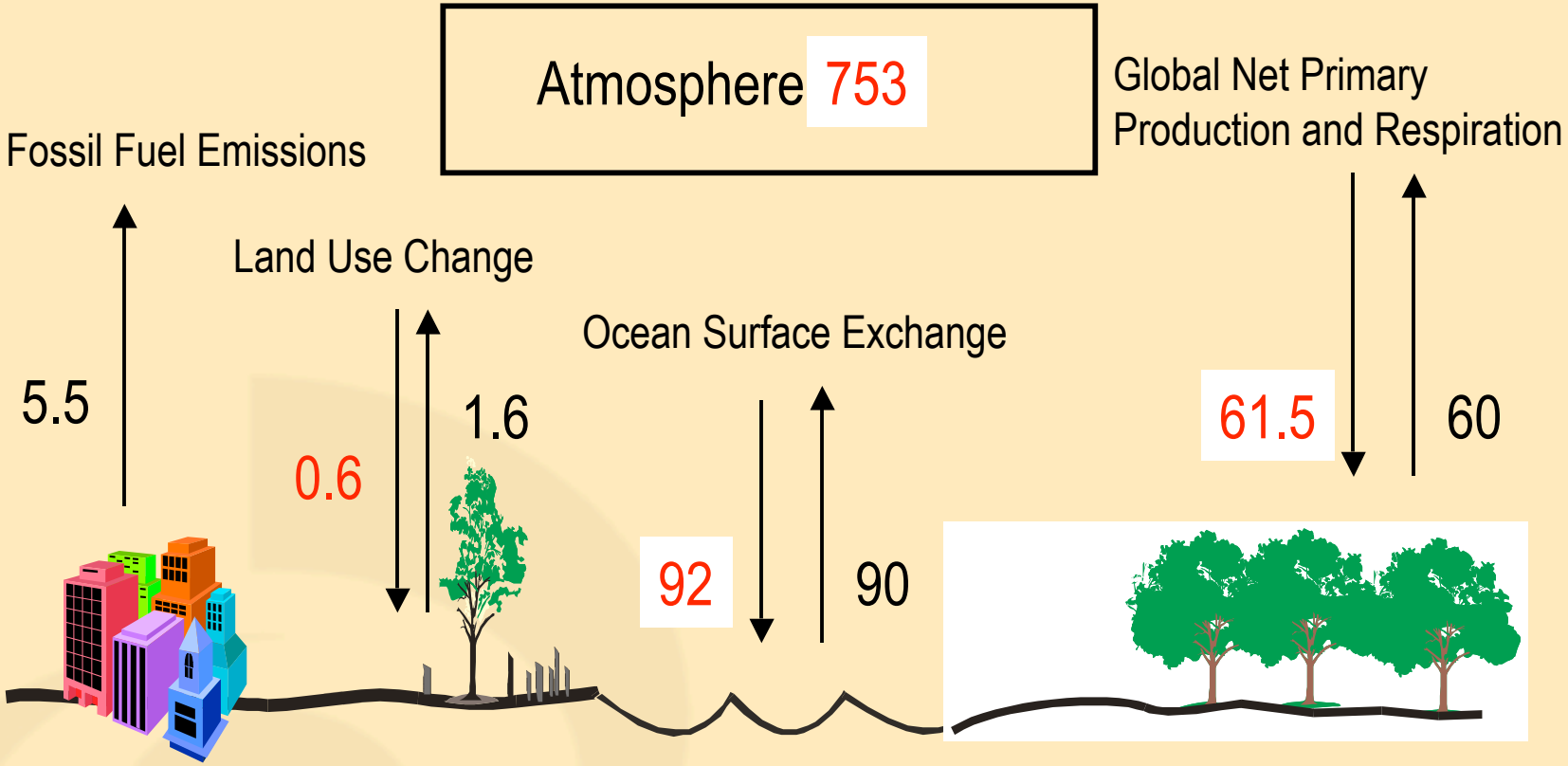
CO_2 Concentrations Projected to Increase





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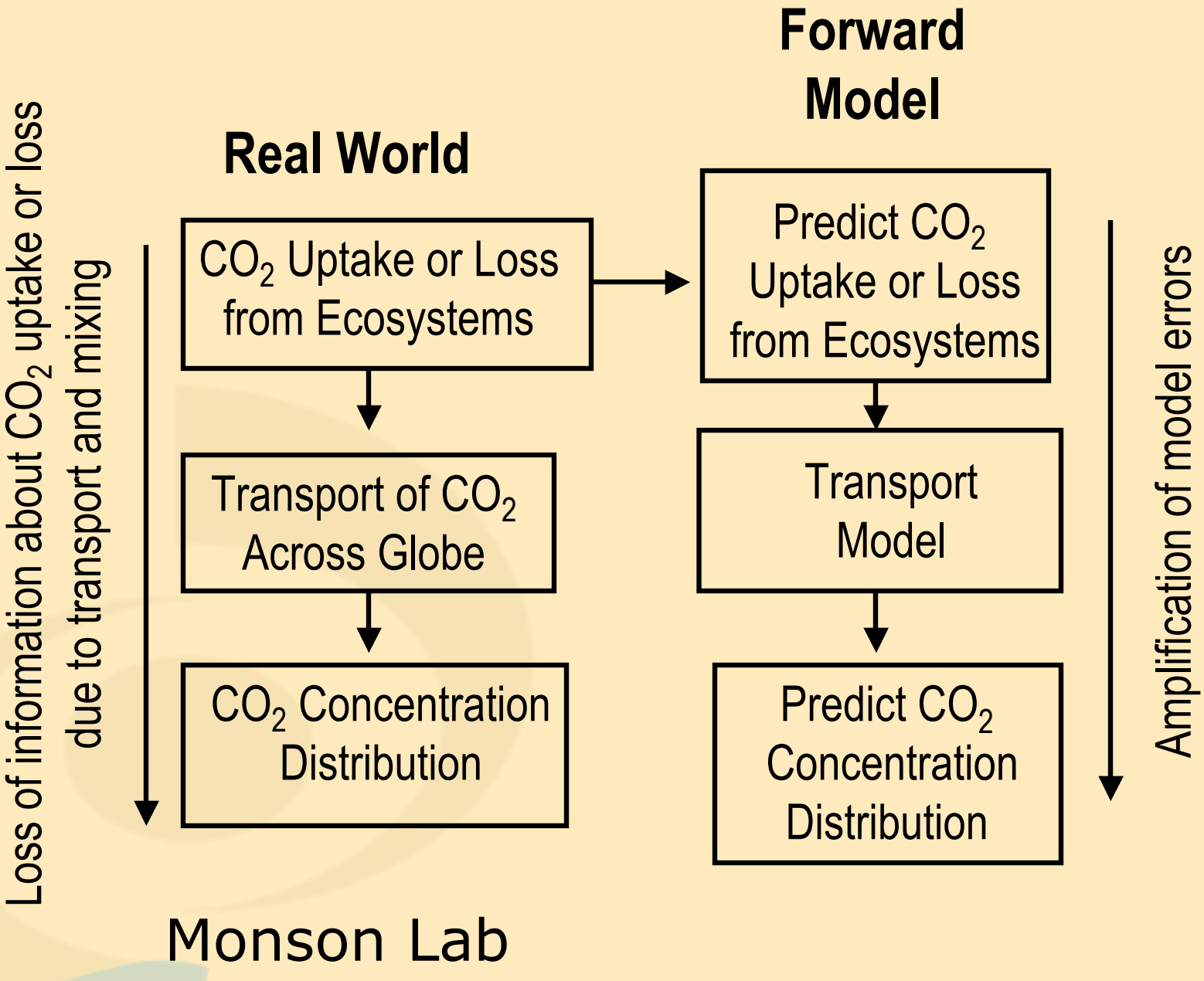
How do we determine how much carbon is going into the oceans, and how much is going into the various terrestrial ecosystems?

1. Measurement -- Aircraft sampling of CO_2 exchange rates over large areas; Use of CO_2 satellite (not currently available)

2. Modeling -- Development of computer simulations of CO_2 exchange over large regions or the entire globe.



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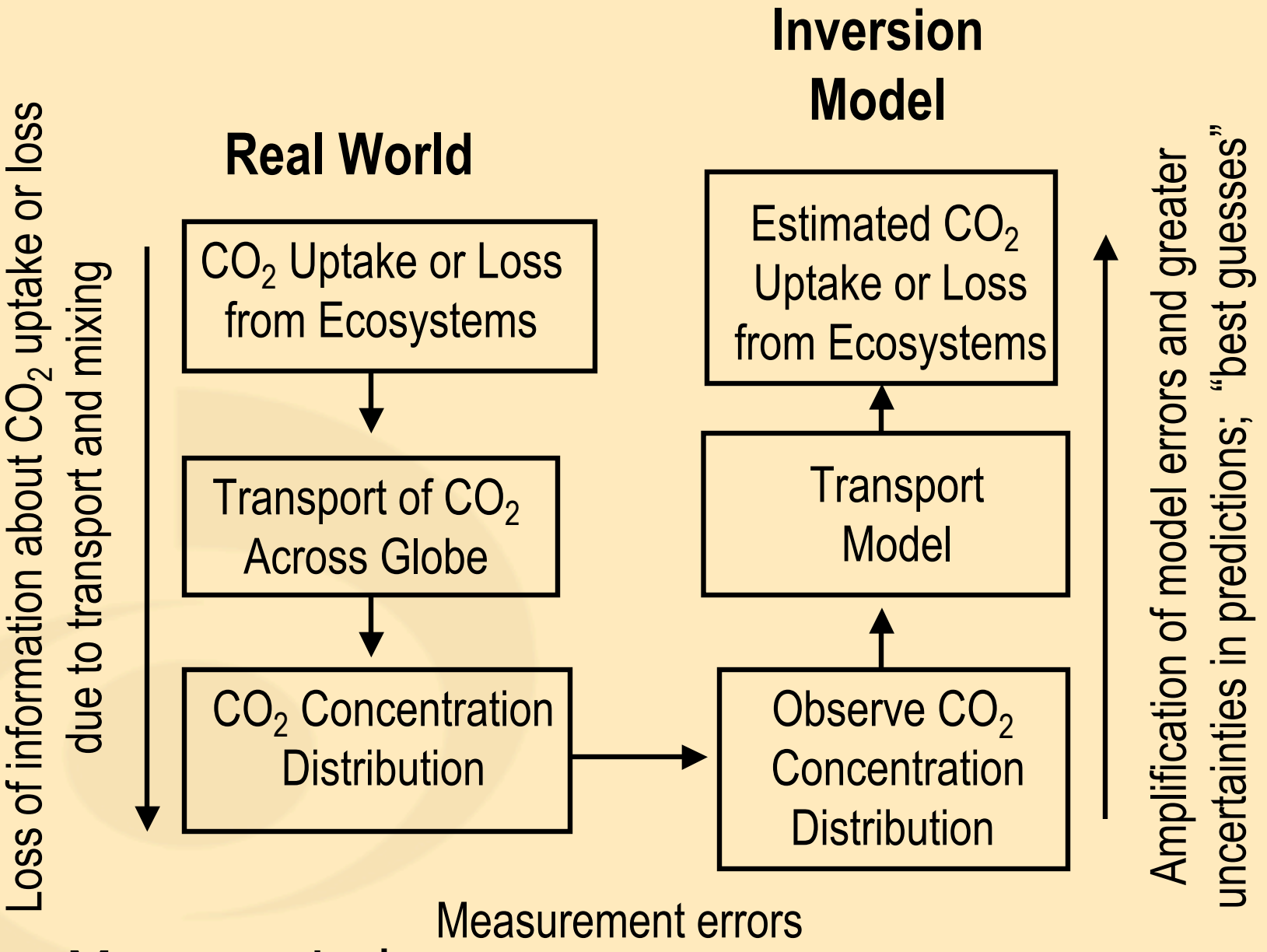

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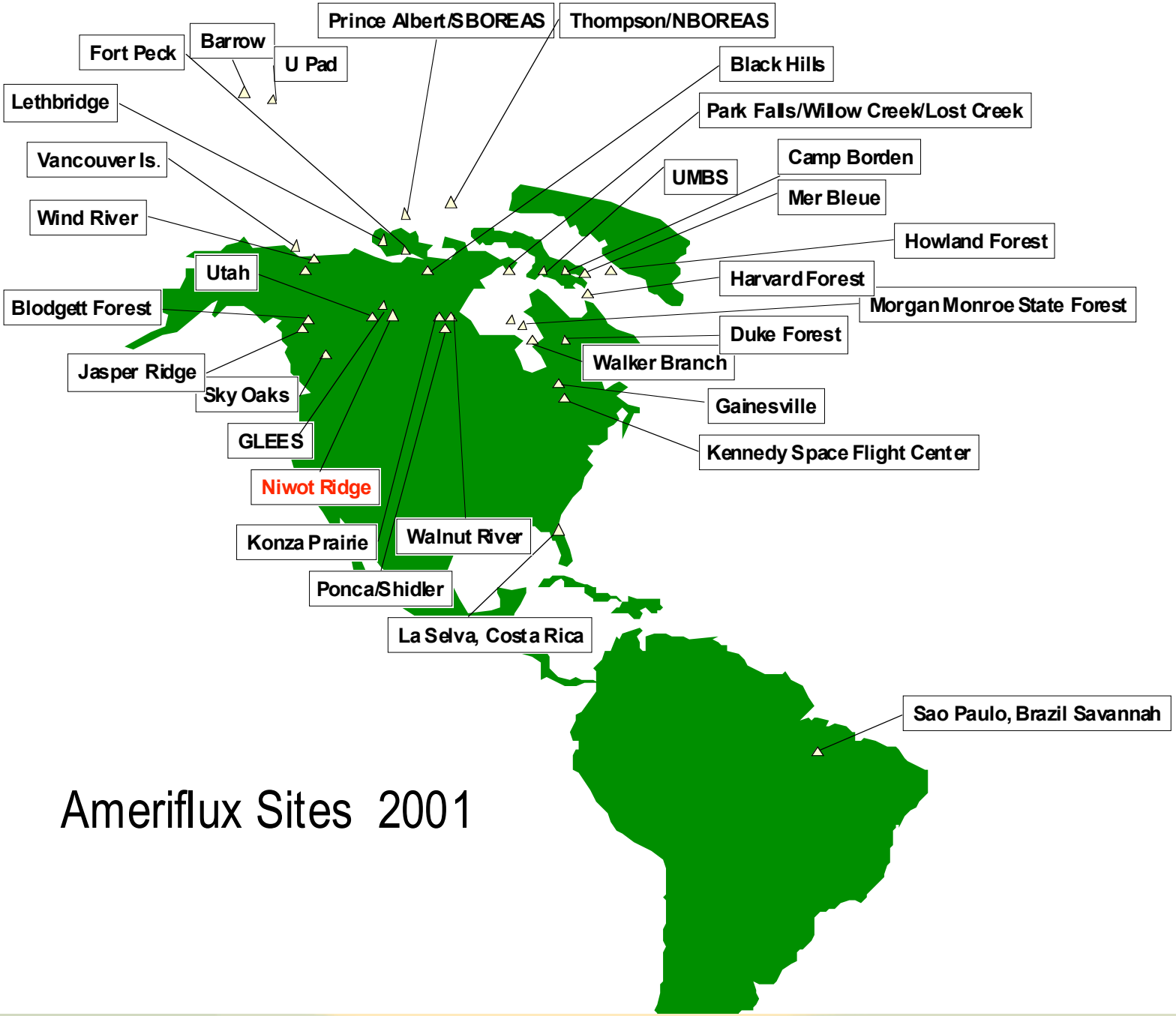
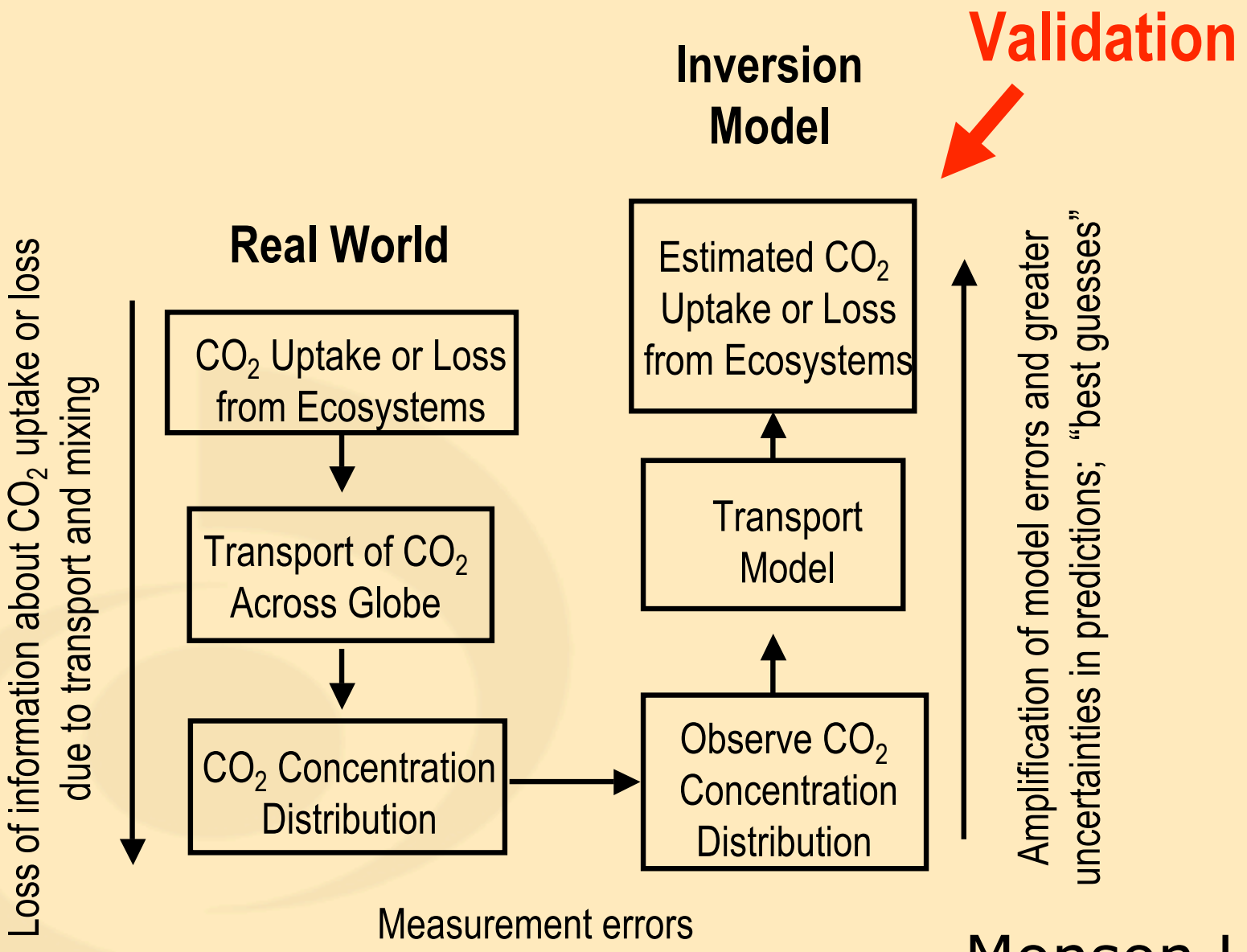


Ameriflux Sites 2001



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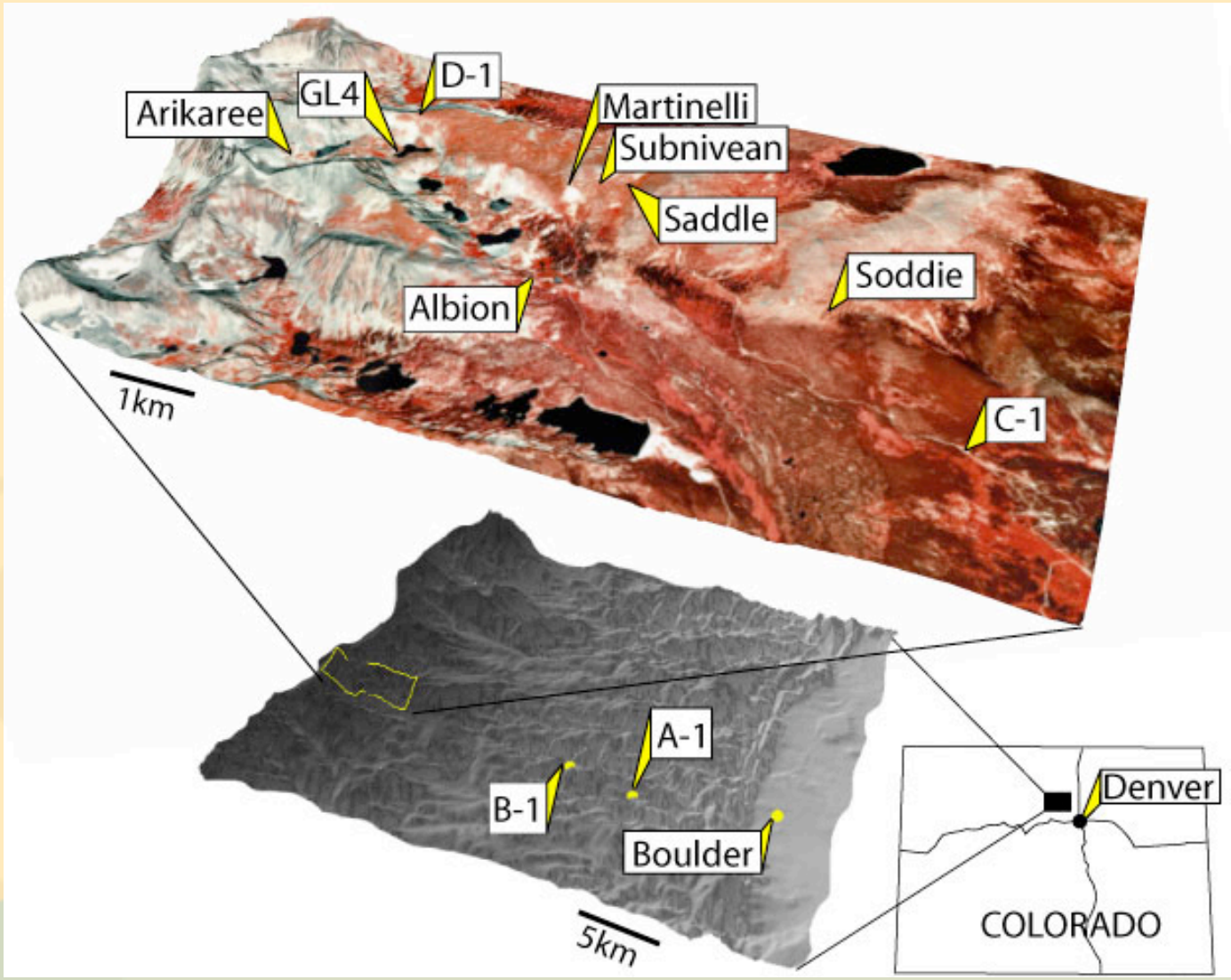
NIWOT RIDGE LTER SITE IN COLORADO, USA



EDDY FLUX INSTRUMENTATION

EDDY FLUX INSTRUMENTATION

- Measures CO2 flux and energy fluxes in 3-dimensions at once
- Frequency of measurements is 20 times each second
- Overcomes problems that cause uncertainty and measurement error
  - air turbulence
  - High-frequency changes in fluxes
- Most accurate method in world

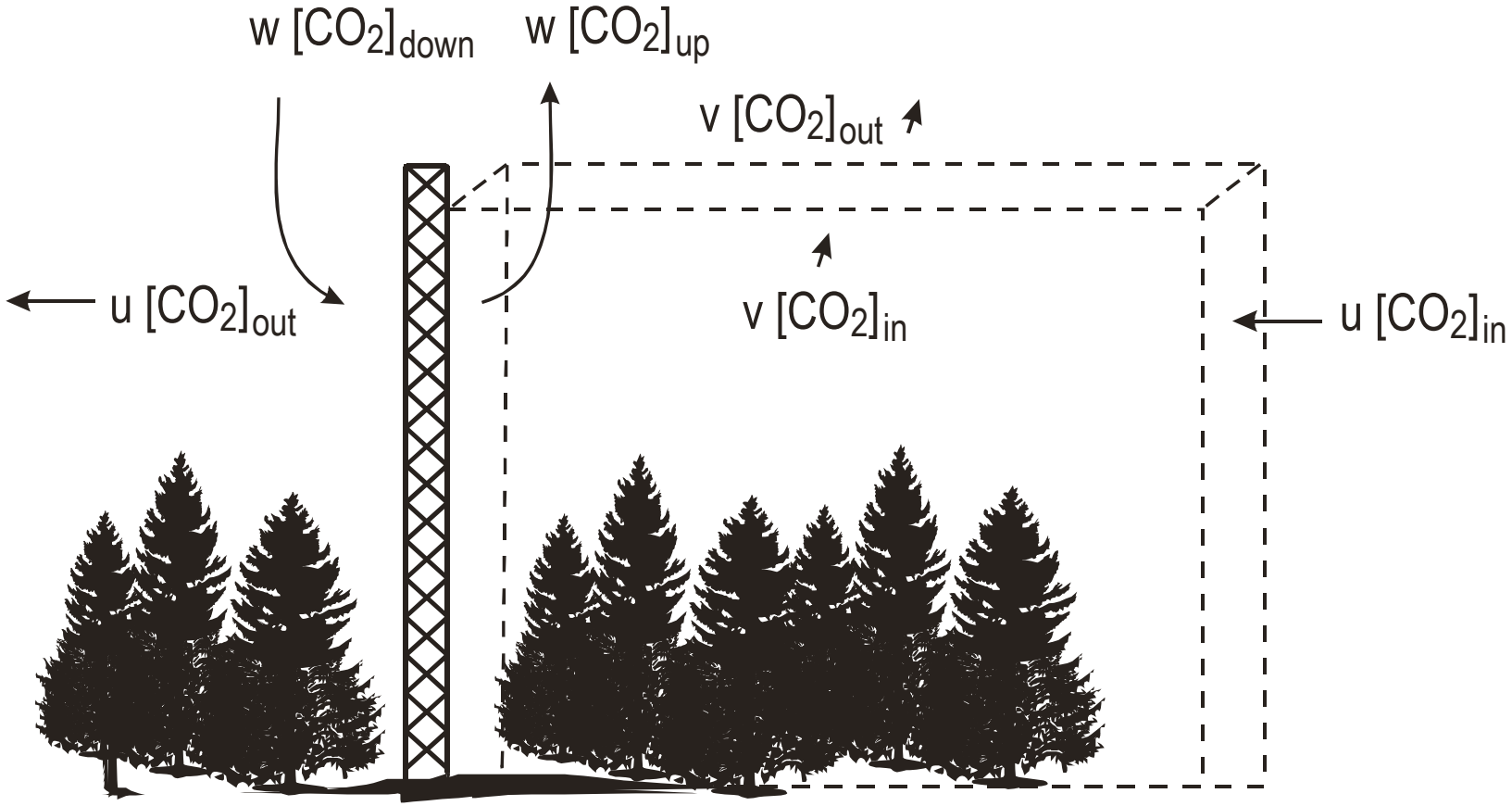
Monson
Ameriflux
site,
Niwot Ridge

Uses full-canopy tower.

Assume: $\overline{u\,[CO_2]_{in}} = \overline{u\,[CO_2]_{out}}$

$\overline{v\,[CO_2]_{in}} = \overline{v\,[CO_2]_{out}}$

Eddy flux= $\overline{w\,[CO_2]_{up}} - \overline{w\,[CO_2]_{down}}$



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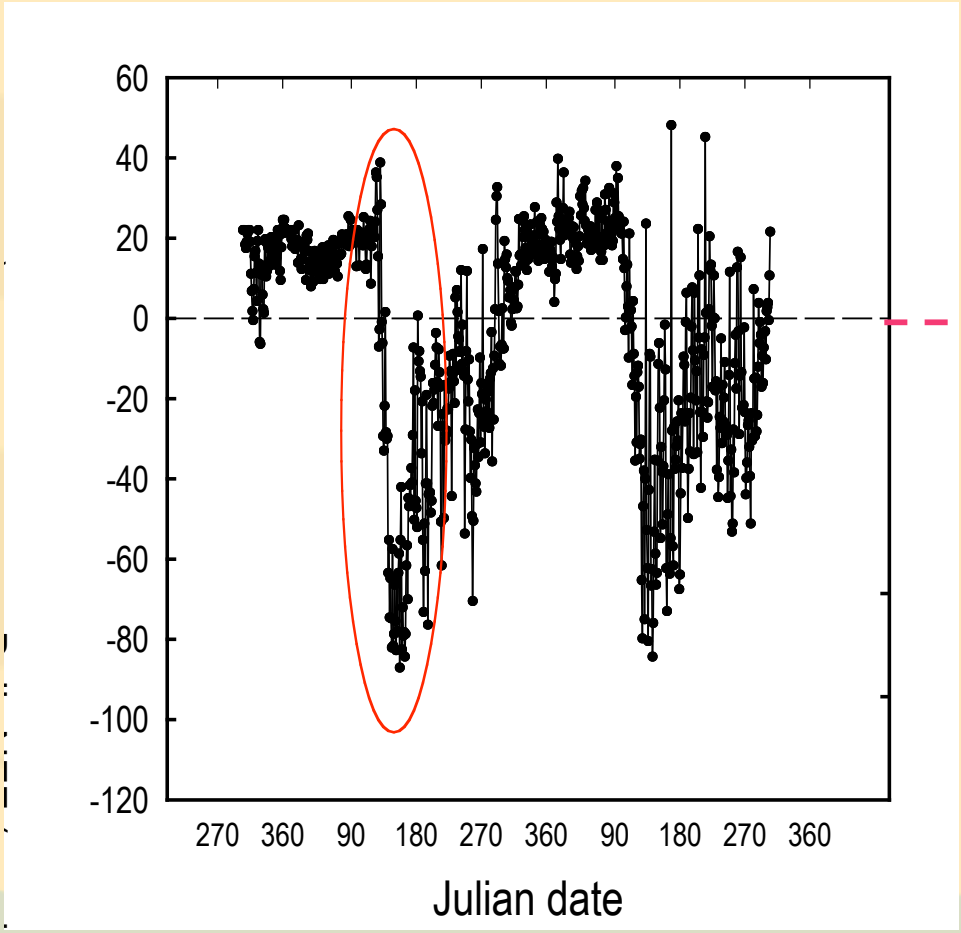
Sharp transition from winter respiration to summer photosynthesis

Net Ecosystem Carbon Exchange
(gC m^{-2} s^{-1})



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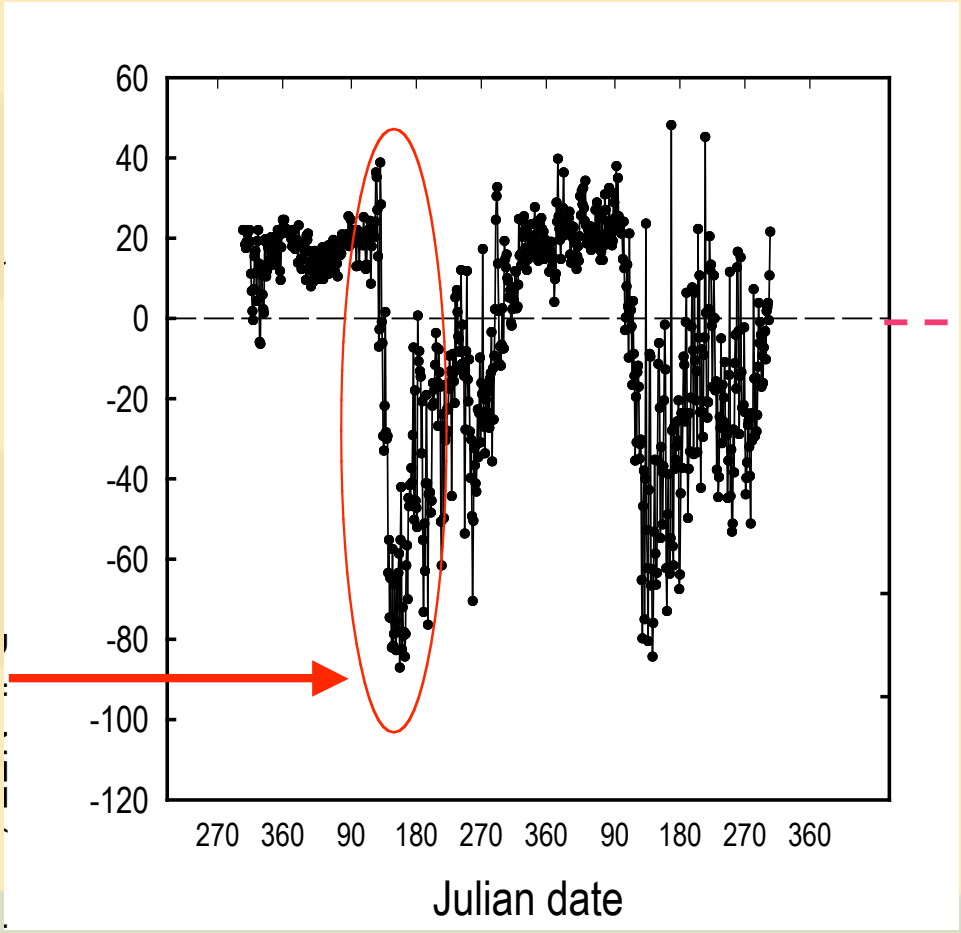
Maximum rates of carbon sequestration occur during snowmelt!!!!!!

Net Ecosystem Carbon Exchange
(gC m^{-2} s^{-1})



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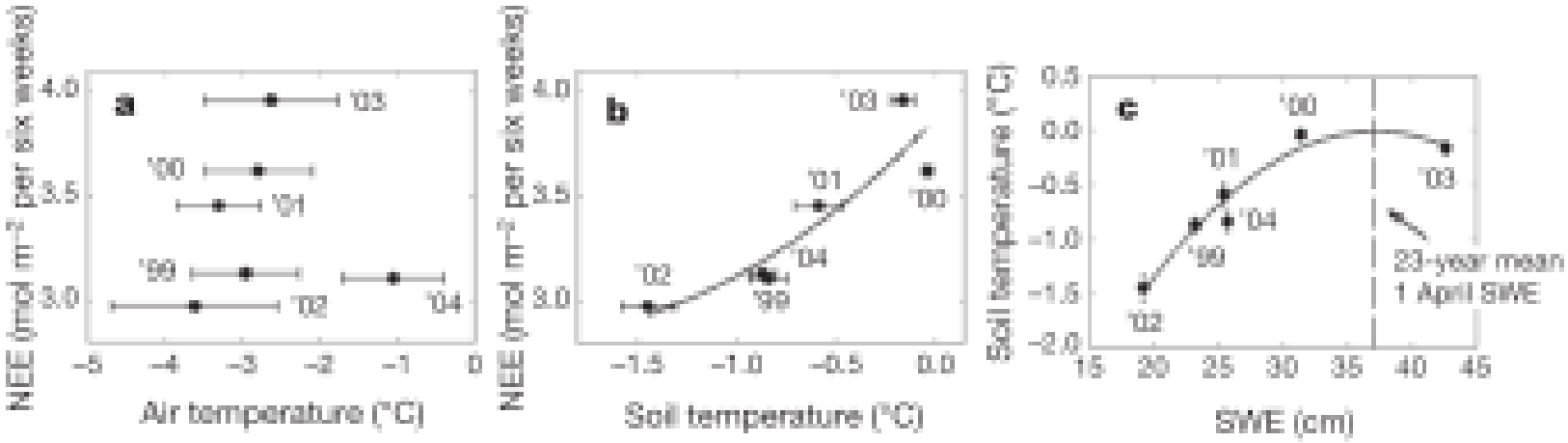
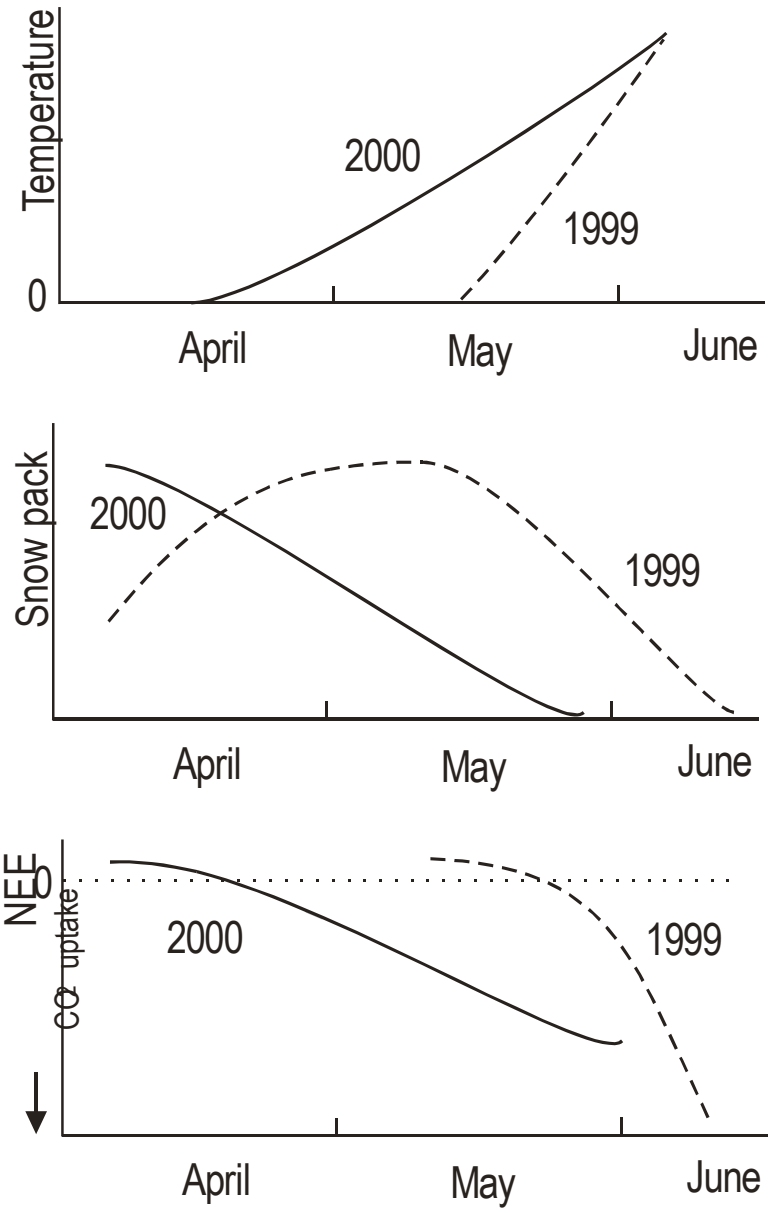
Climate Controls over NEE

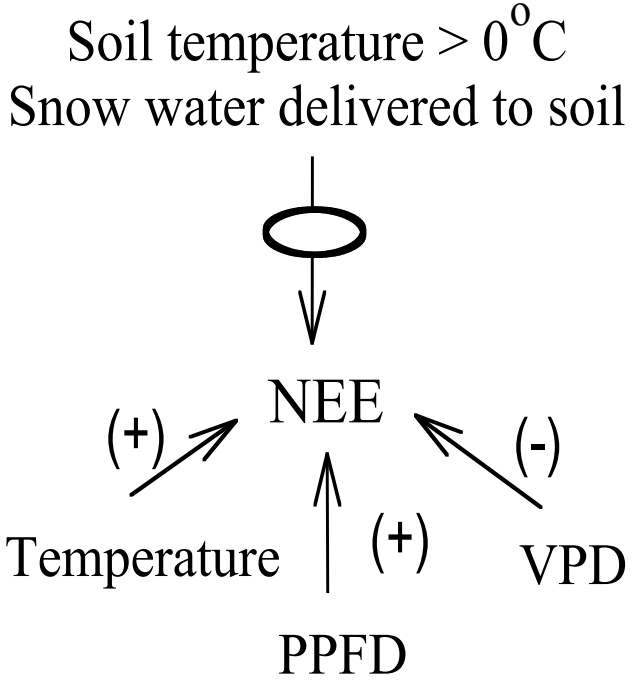


Less snow means colder soils.
Colder soils mean less NEE.
Earlier snowmelt results in less NEE

Monson et al., 2006a, Nature



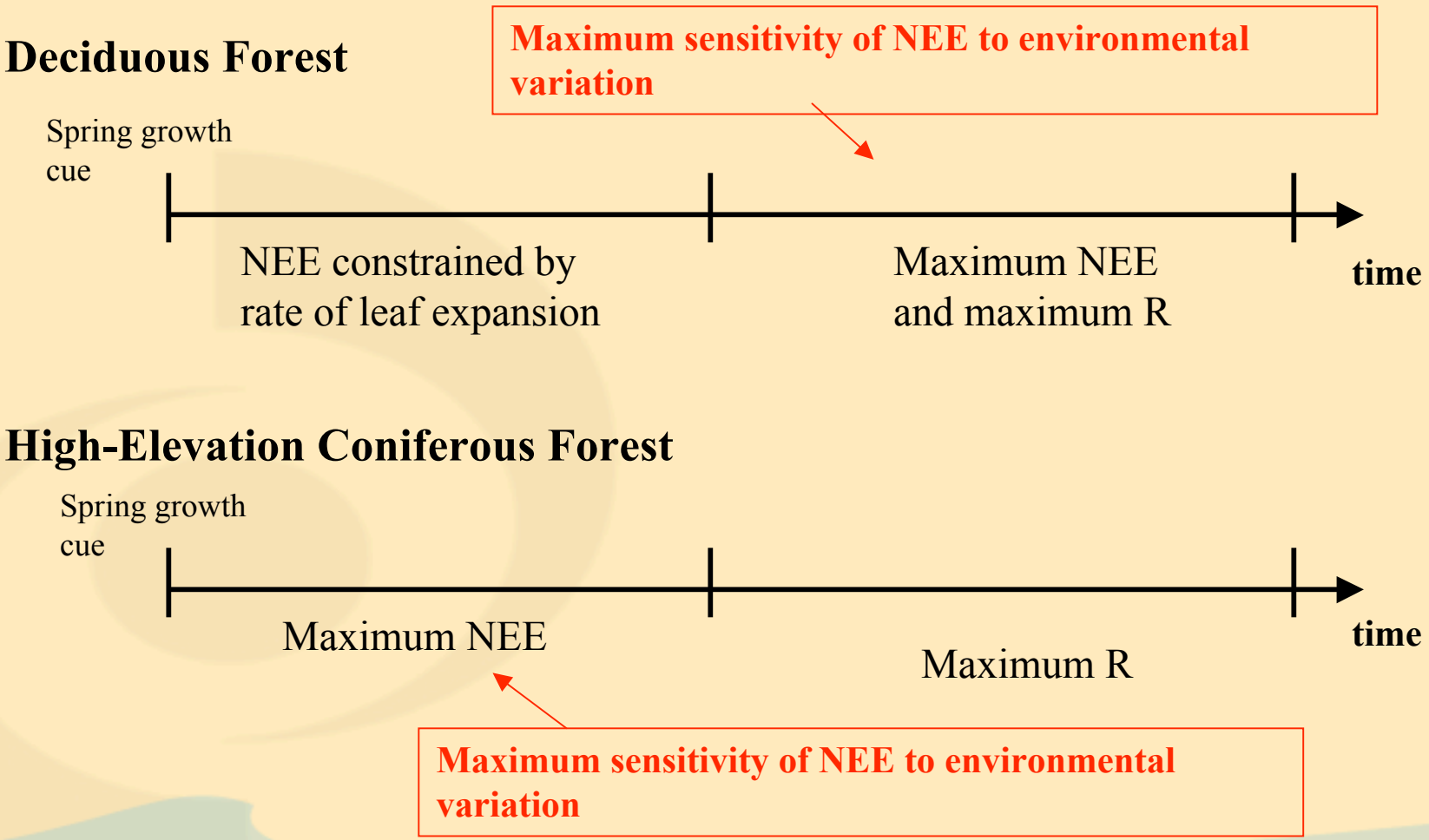
Springtime Control Over NEE



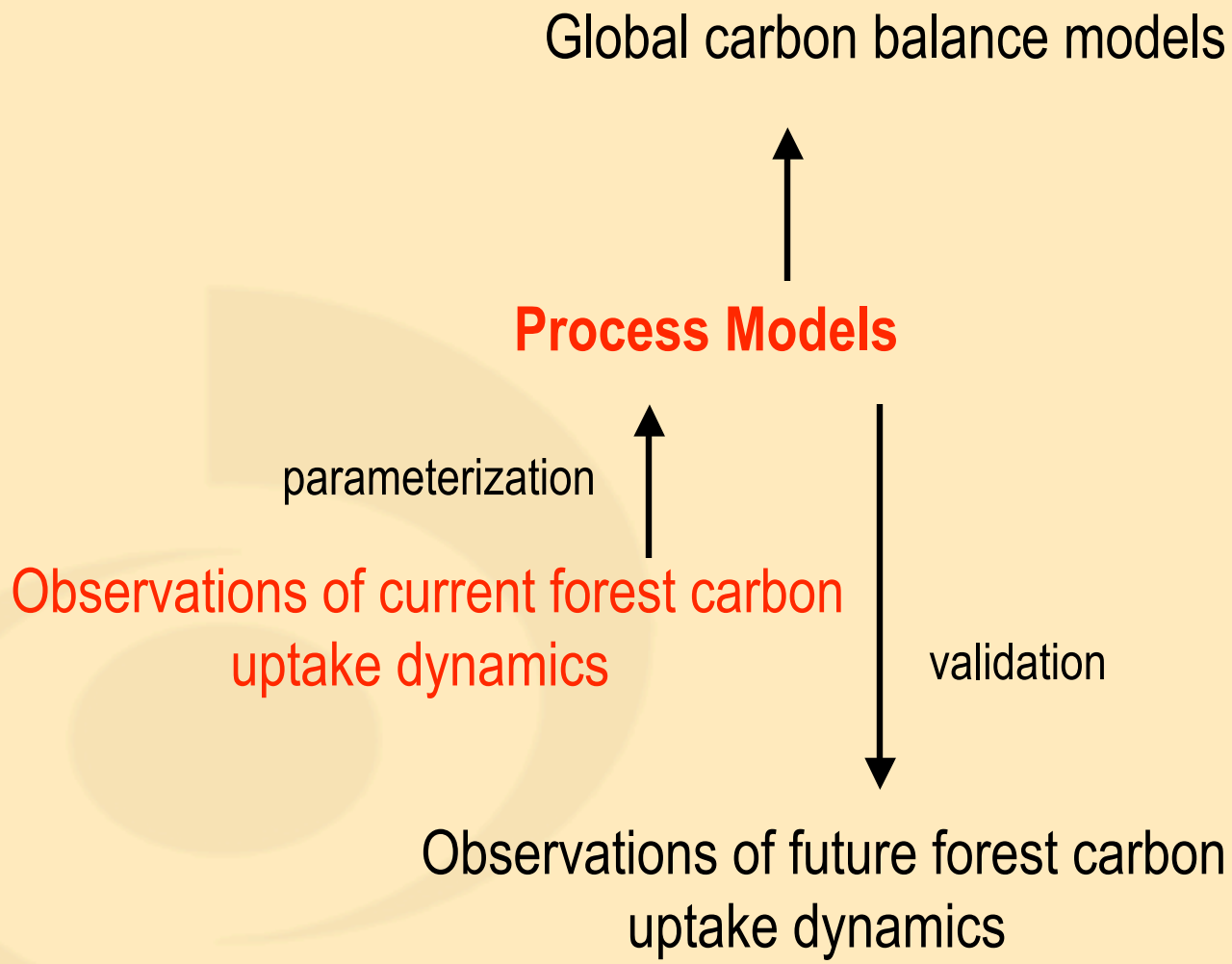
Effects of Early Spring Warm-Up on Annual NEE

- Goulden et al. (1996) = Early spring warm-up **increased** annual NEE by 2X (northeastern deciduous forest)
- Chen et al. (1999) = Early spring warm-up **increased** annual NEE by 1.5X (boreal aspen forest)
- Monson et al. (2001) = Early spring warm-up **decreased** annual NEE by 0.6 X (high-elevation coniferous forest)

Effects of Early Spring Warm-Up on Annual NEE



Improvement of Bottom-Up Models



SNOW MOLDS

More microbial biomass under snow than in summer

Temp. interval	Q_{10} rate
isolate 319-1	
-2 – 0	320.0
0 – 4	2.1
isolate 317-1	
-2 – 0	144.3
0 – 4	1.2
isolate 316-1	
-2 – 0	5.4
0 – 4	4.7

Schmidt, Wilson, Meyer, Gebauer. In review, Biogeochem)

Q10 rates

All models:
↓ Q10 with ↓Tair

"Our" results:
↑↑↑ Q10 with Tair
below 0°C

WHY GCM RESULTS WRONG

- Q10 rates an integral part of land-atmosphere models
- As temperature increases, Q10 increases and NEE/NPP increases
- Our results show that there Q10 rates in seasonally snow-covered areas INCREASE from -2°C to 0°C

Summary 1

- Maximum net photosynthesis of subalpine forests occurs during snowmelt!
- The transition from net respiration to net photosynthesis occurs in less than a week
- More microbial activity under snow than in the summer
- Decreasing snowpack causes colder soil temperatures, reducing microbial activity, and decreasing biogeochemical cycling

Summary 2

- Snow at risk: areas near 0°C
- Less snow means colder soils
  - Less insulation
- Colder soils mean less microbial activity
- Less microbial activity may have large affect on global carbon cycle
- More snow in Arctic may enhance microbial activity

THRESHOLDS AND CLIMATE CHANGE

Mountain Pine Beetle outbreak Western US

Romme et al., CSU

Whitebark Pines, YNP

New York Times, January 2007

Grizzly bear food source

PROBLEM

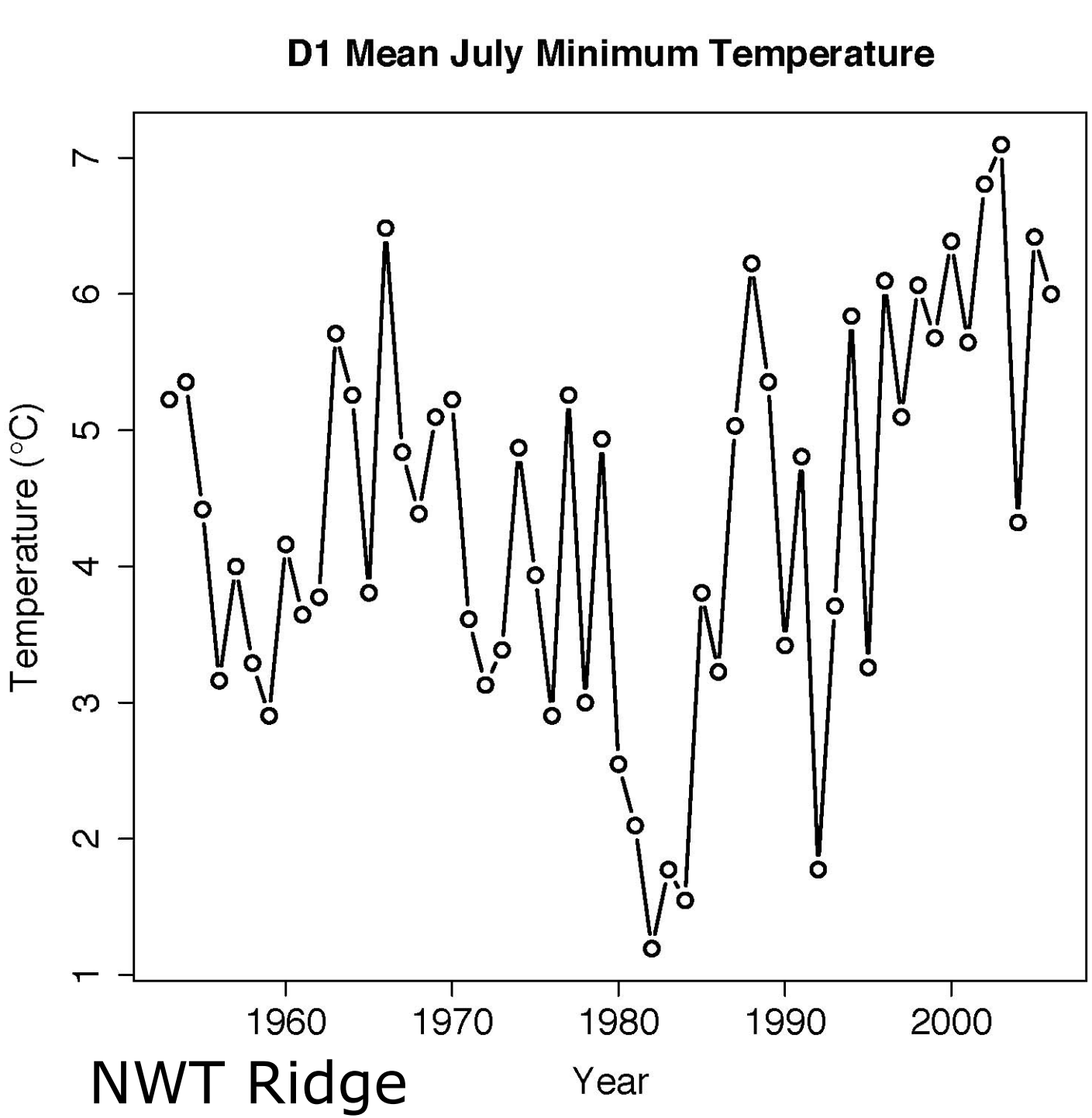
- A widespread and fast moving mountain pine beetle epidemic (MPB; *Dendroctonus ponderosae*) is occurring in coniferous forests of the western US.
- Severe outbreaks are occurring in watersheds from New Mexico through British Columbia, where forests are converted from a net carbon sink to a large carbon source.

WHY WE CARE

- The impacted forests are critical headwater regions where snowfall is the dominant type of precipitation
- Raising concerns about
  - water quantity
  - Water quality
  - Flooding
  - Erosion
  - Increased forest fires
- The MPB epidemic is likely to have far-reaching consequences for both ecological and human systems

THE CAUSE

- Climate change
- Warmer summers cause
  - Drought stress on subalpine forests
  - Defense of trees against beetles decrease
- Mountain Pine beetle endemic
- Hot and dry summers cause trees to lose resiliency against the pest
- Might this happen in Europe?


D1 Mean July Minimum Temperature
Temperature (°C)
1
2
3
4
5
6
7
1960
1970
1980
1990
2000
Year
NWT Ridge

Colorado Front Range is next

BOMBS AWAY! A plane drops fire retardant onto the Bobcat Gulch Fire in Big Thompson Canyon (Sherri Barber photo, The Coloradoan)

Krummholz

MPB at higher elevations than historically

Limber pine and other treeline species at risk

Summary

- Mature lodgepole pine in the Front Range is toast
- Mountain Pine Beetle moving to higher elevations because of warming
- Treeline may move down in elevation because of five-needle pine mortality
- Warming temperatures may cause a decrease in the elevation of treeline

Additional research

- M. I. Litaor, M. W. Williams, and T. Seastedt, *Topographic controls on snow distribution, soil moisture, and species diversity of herbaceous alpine vegetation, Niwot Ridge, Colorado*, JGR: Biogeosciences, in press.
- John D. Marshall, John M. Blair, Deb Peters, Greg Okin, Albert Rango, Mark Williams, *Predicting and Understanding Ecosystem Responses to Climate Change at Continental Scales*, Frontiers in Ecology and the Environment, in press.