NSTA WEB SEMINARS

LIVE INTERACTIVE LEARNING @ YOUR DESKTOP

UCAR: Teaching Climate with Models: Breathing of the Earth

Presented by: Randy Russell and Scott Denning

June 11, 2012

Teaching Climate with Models: Breathing of the Earth

Scott Denning

Randy Russell

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- Director of Education, Center for Multiscale Modeling of Atmospheric Processes (CMMAP)
- BS in Geology, PhD in Atmospheric Science

CMMAP
Reach for the sky.

Colorado State University

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UCAR science education

- Spark is the science education group at the National Center for Atmospheric Research (NCAR)
- BS astrophysics, MS aerospace engineering, PhD in education

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Understanding and Prediction: Modeling the Earth System

This is the first in a series of four webinars in which we will use very simple models to explore the way the Earth's climate works and how it's changing.

- The Breathing of the Earth: Carbon cycling among the land, ocean, and atmosphere
- Heating and Warming: The sensitivity of the Earth's climate to atmospheric CO2
- Challenges for Our Children: Projections of the future of Earth's climate and carbon cycle
- Opportunities for Abundance: Solving the problems of energy, carbon, and climate

What is a Model? Why use Models?

- ❖ Models are idealized or simplified representations
- ❖ Models help us to explain the essential aspects of things or processes in the real world
- ❖ We can experiment with models to learn how things work
- ❖ Models can (sometimes) help us predict the future!

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```
z2(:) = 0.
do i=1,ndim
  do j=1,ndim
    z2(i) = z2(i) + v_1d(i,j)*xgj(j)/sqrt(r_1d(j))
  enddo
enddo

xnorm(niter)=0.
do i=1,ndim
  xnorm(niter) = xnorm(niter) + z2(i)*z2(i)
enddo
xnorm(niter) = sqrt(xnorm(niter))
!
deallocate (zvar_obs)
deallocate (zvar_obs_ad)
deallocate (xjo_obs)
!
```

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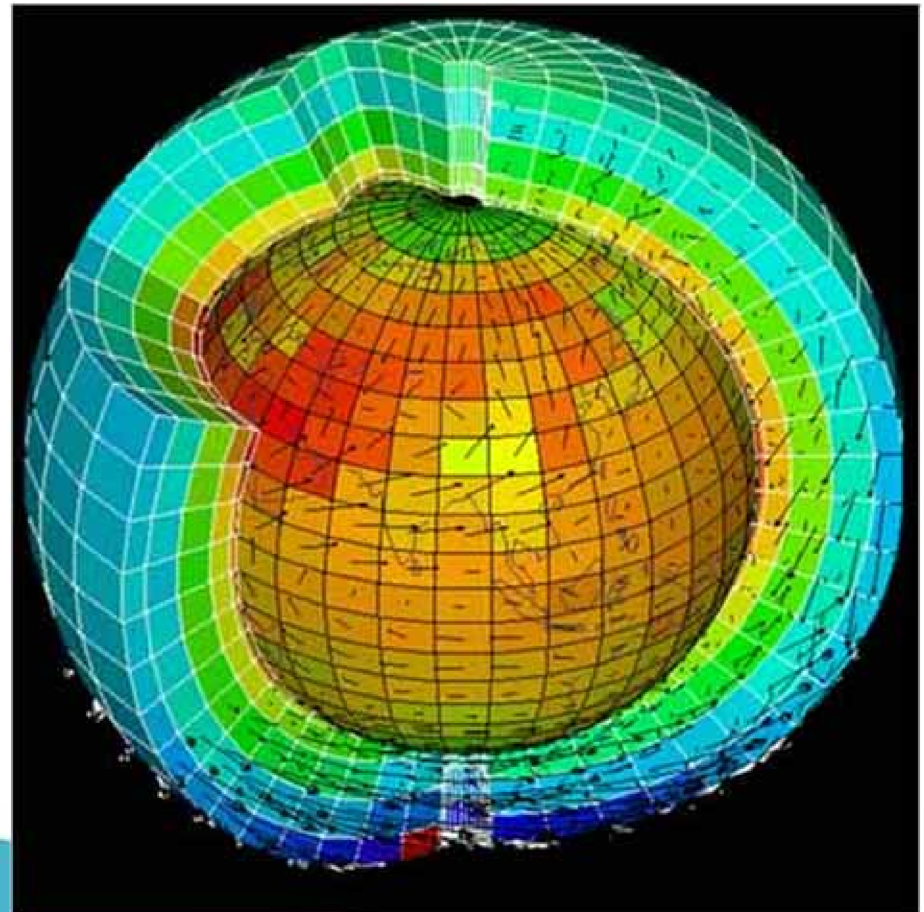

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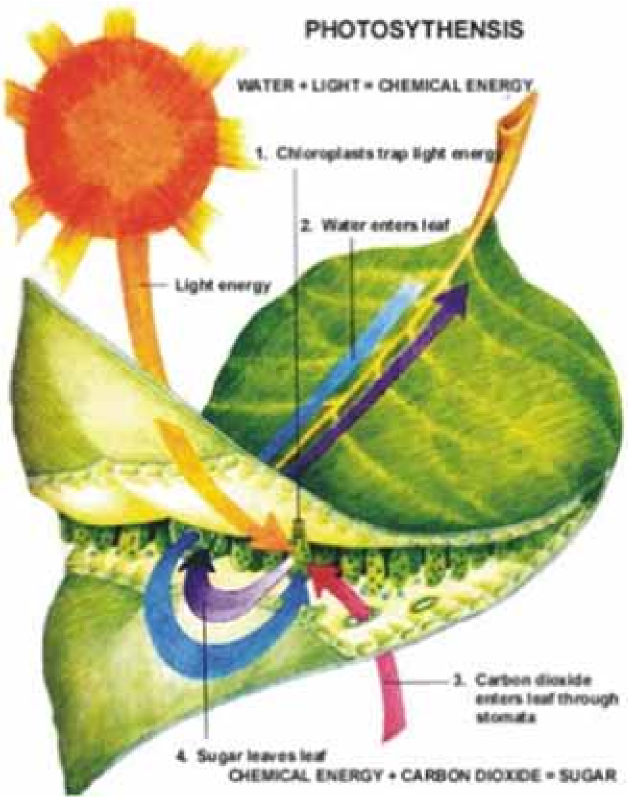
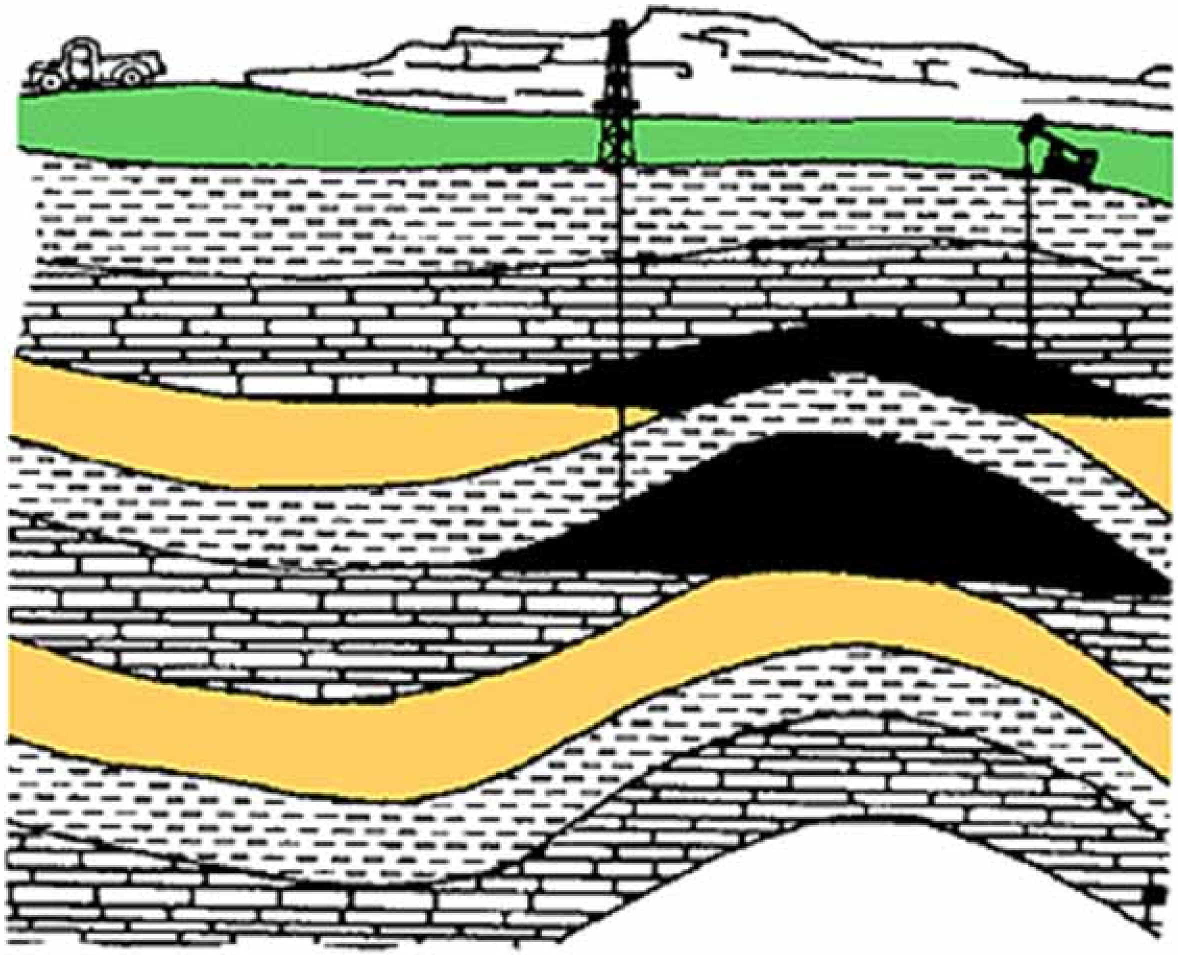
Carbon, Life, and Energy



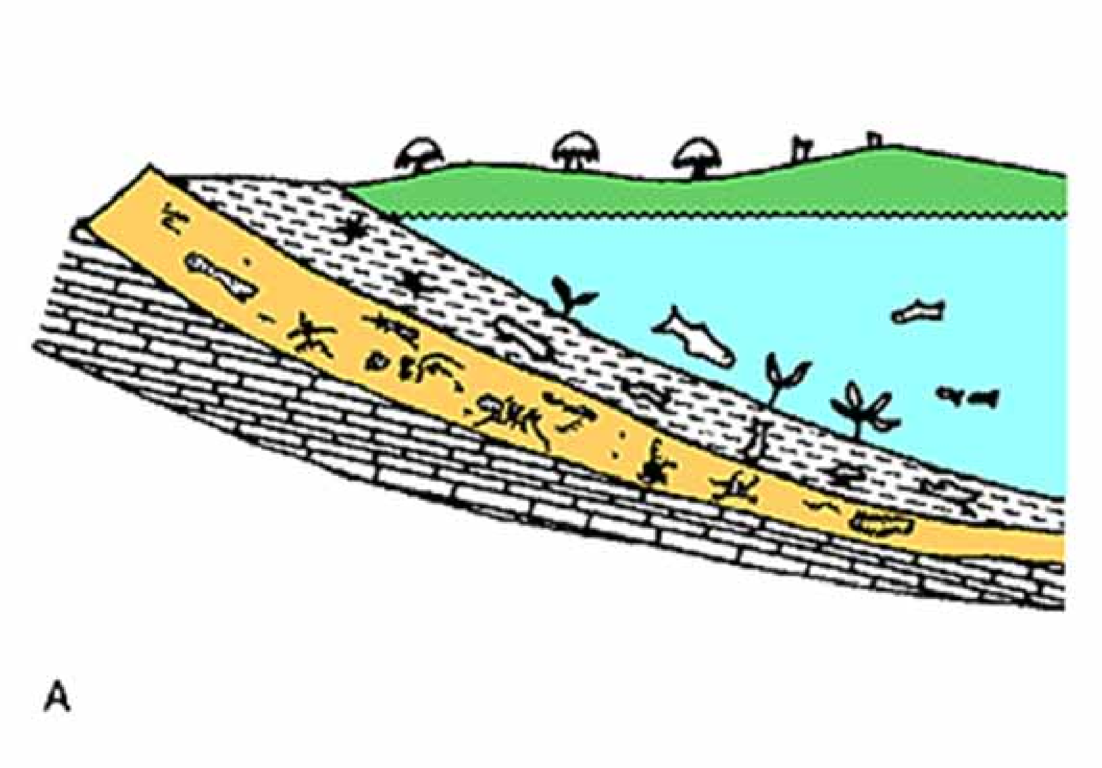
- Photosynthesis uses energy from the Sun to **convert inorganic air (CO_2) to living biomass!**
- Individual carbon atoms are "strung together" like beads on a string to form longer chain organic molecules
- Energy from the Sun is stored in the chemical bonds between carbon atoms in each organic molecule
- Most of this energy is released through respiration (back to CO_2) when plants are eaten by animals, bacteria, people

Fossil Fuels



Some of the stored solar energy in biomass can be preserved in fossilized remains

Fossil Fuels



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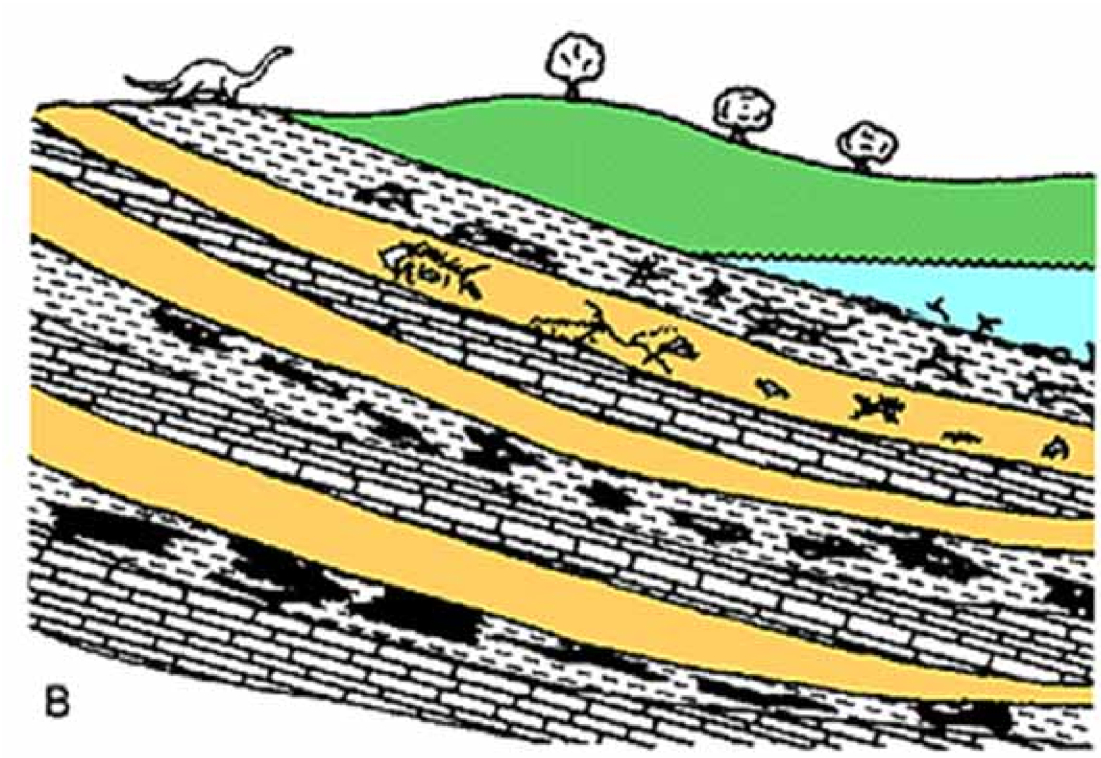

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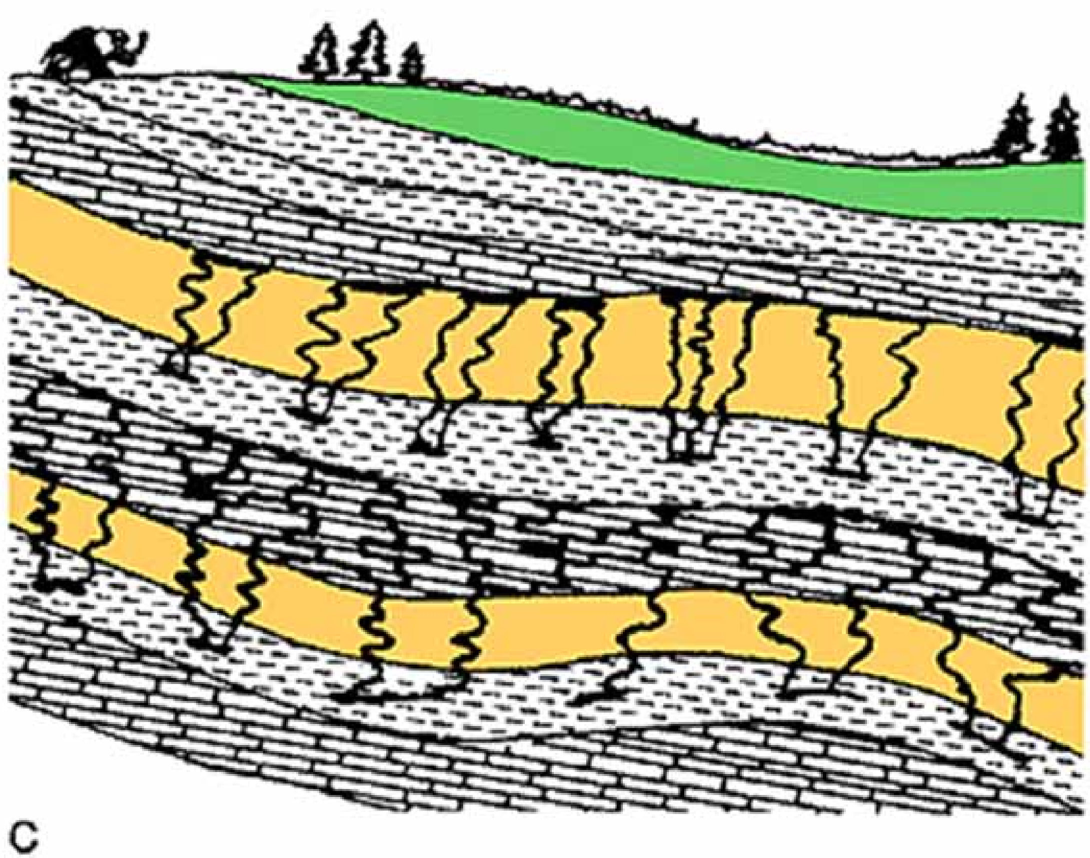

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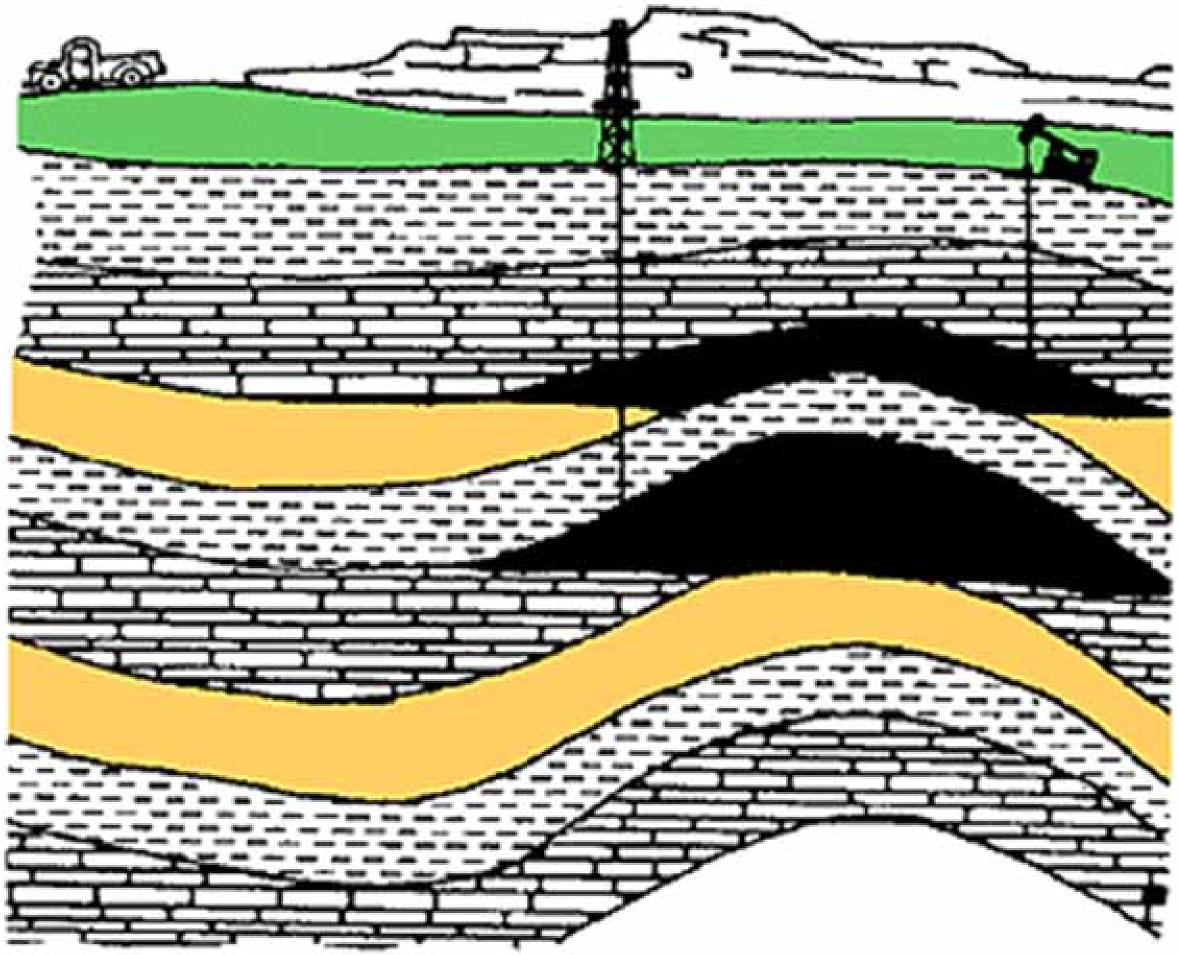

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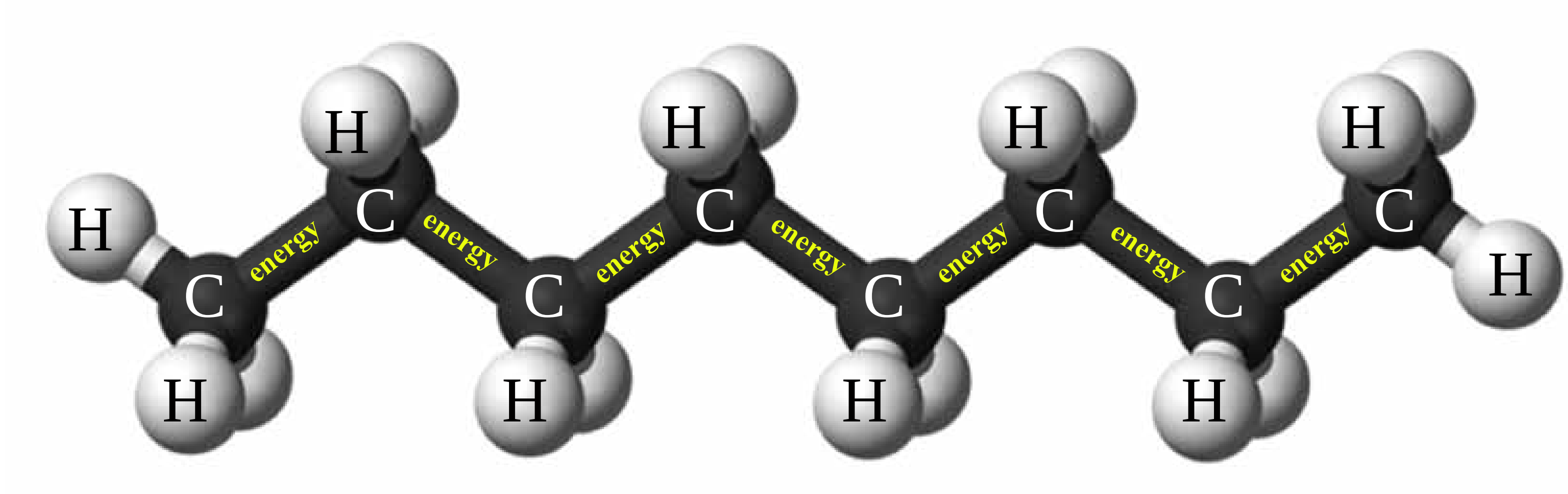
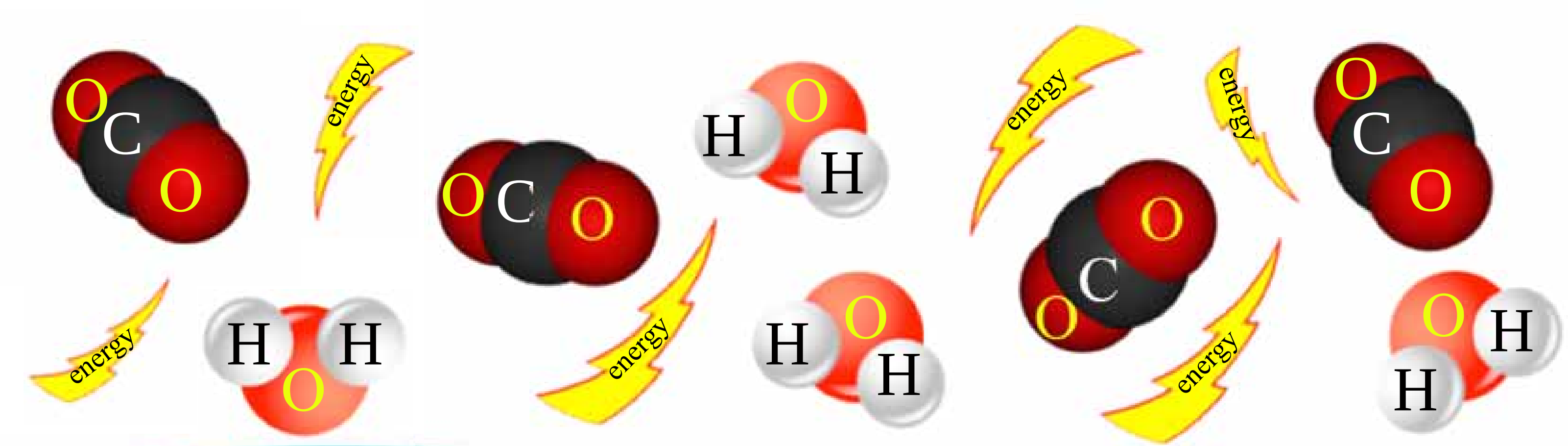
Hydrocarbons, Energy, and CO_2



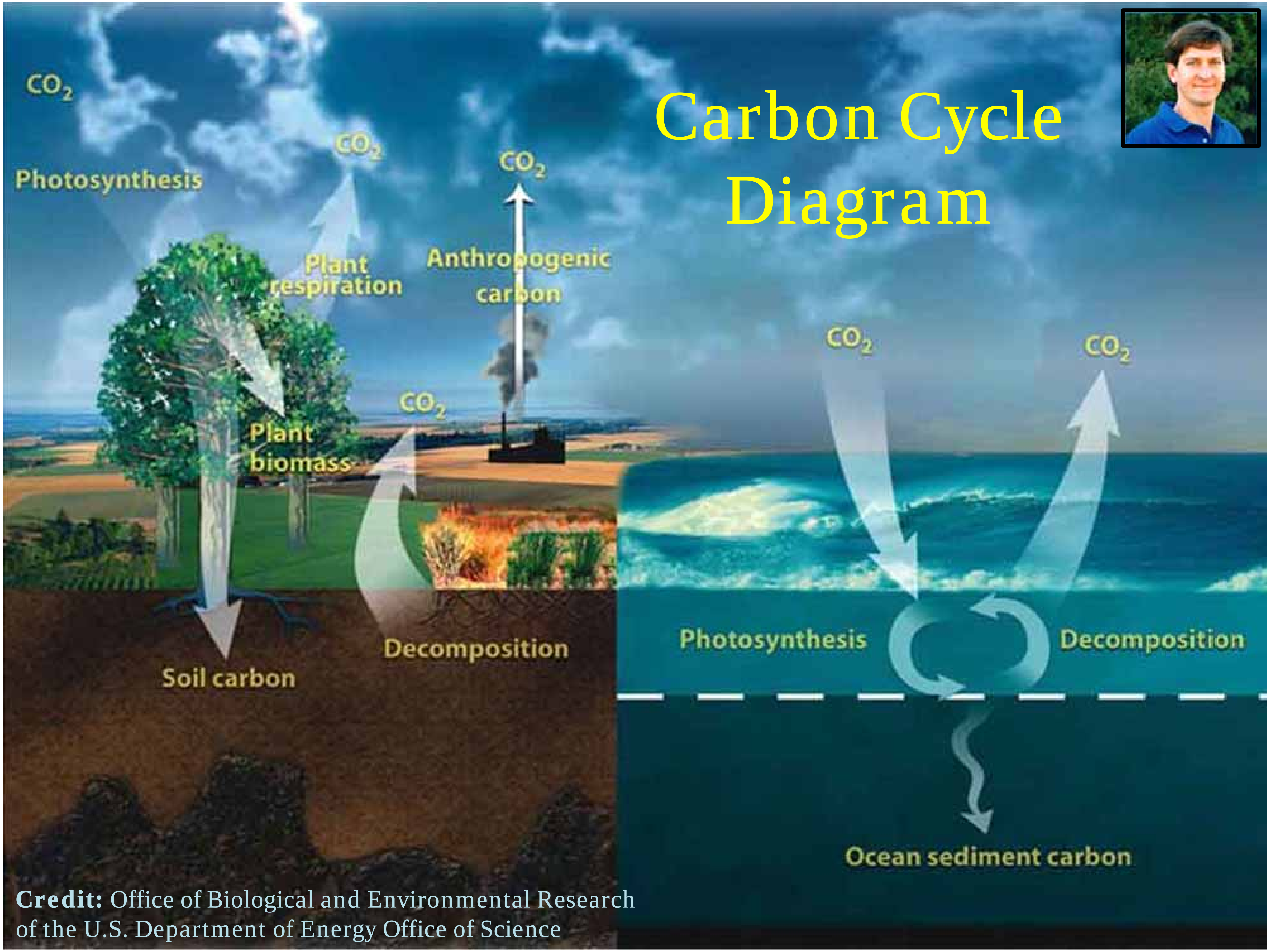
We dig this stuff up and burn it, harvesting the stored energy to power civilization





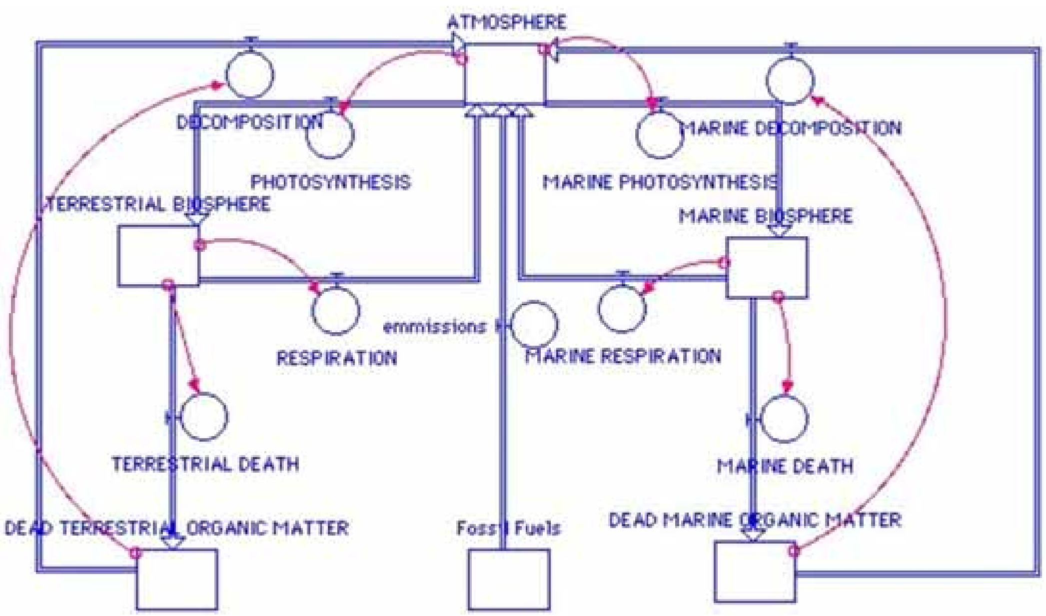
Questions?

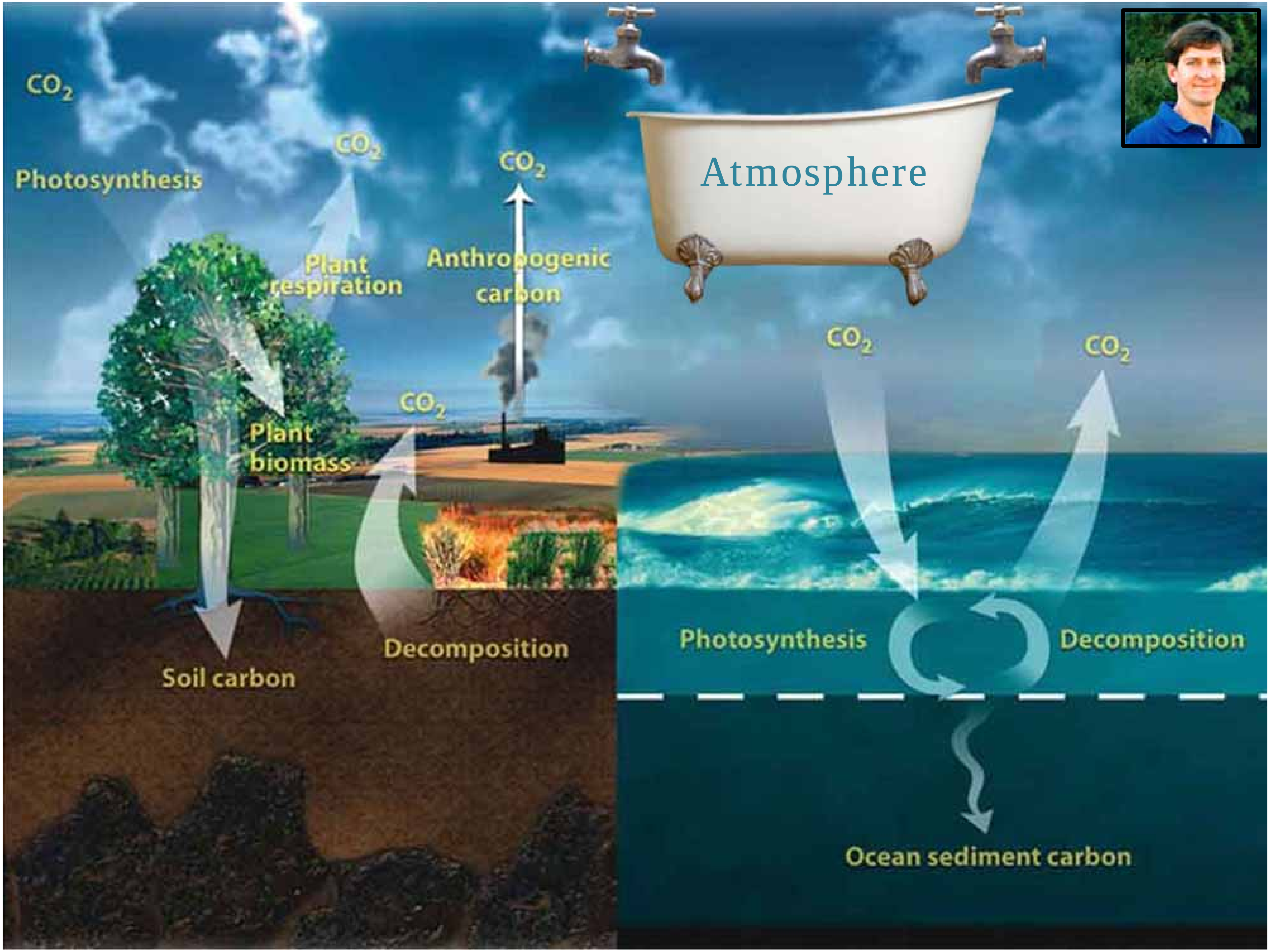
Carbon Cycle Diagram



Credit: Office of Biological and Environmental Research of the U.S. Department of Energy Office of Science

Stocks & Flows Models (e.g. STELLA)





CO2
Photosynthesis
CO2
Plant respiration
CO2
Anthropogenic carbon
Atmosphere
Plant biomass
CO2
Soil carbon
Decomposition
CO2
CO2
Photosynthesis
Decomposition
Ocean sediment carbon

Bathtub Model

- “Bathtub Dynamics: Initial Results of a Systems Thinking Inventory” (2000) L. Booth Sweeney & John D. Sterman
- “Understanding Public Complacency About Climate Change: Adults' mental models of climate change violate conservation of matter” (2007) John D. Sterman & L. Booth Sweeney

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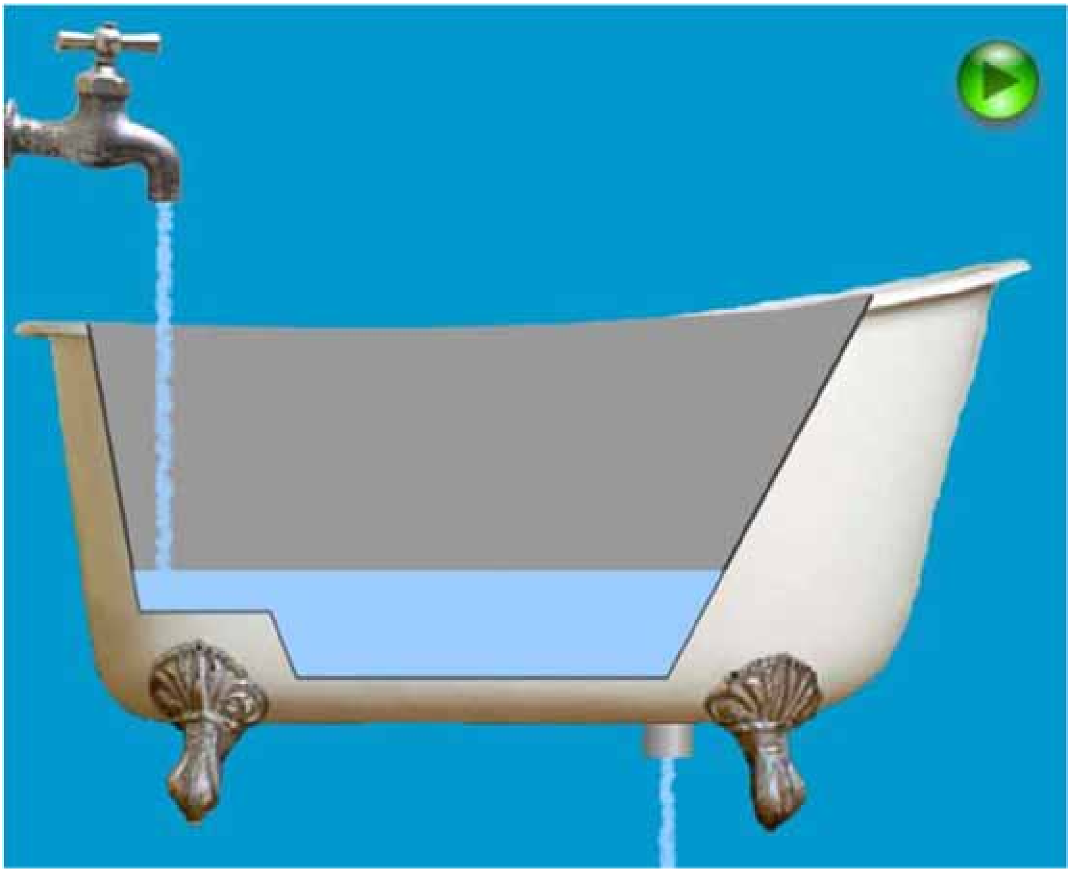
Using Models in Education

"Essentially, all models are wrong, but some models are useful."

\- George E. P. Box (1951)

Natural Equilibrium (pre-industrial)
Average flow in = Average flow out



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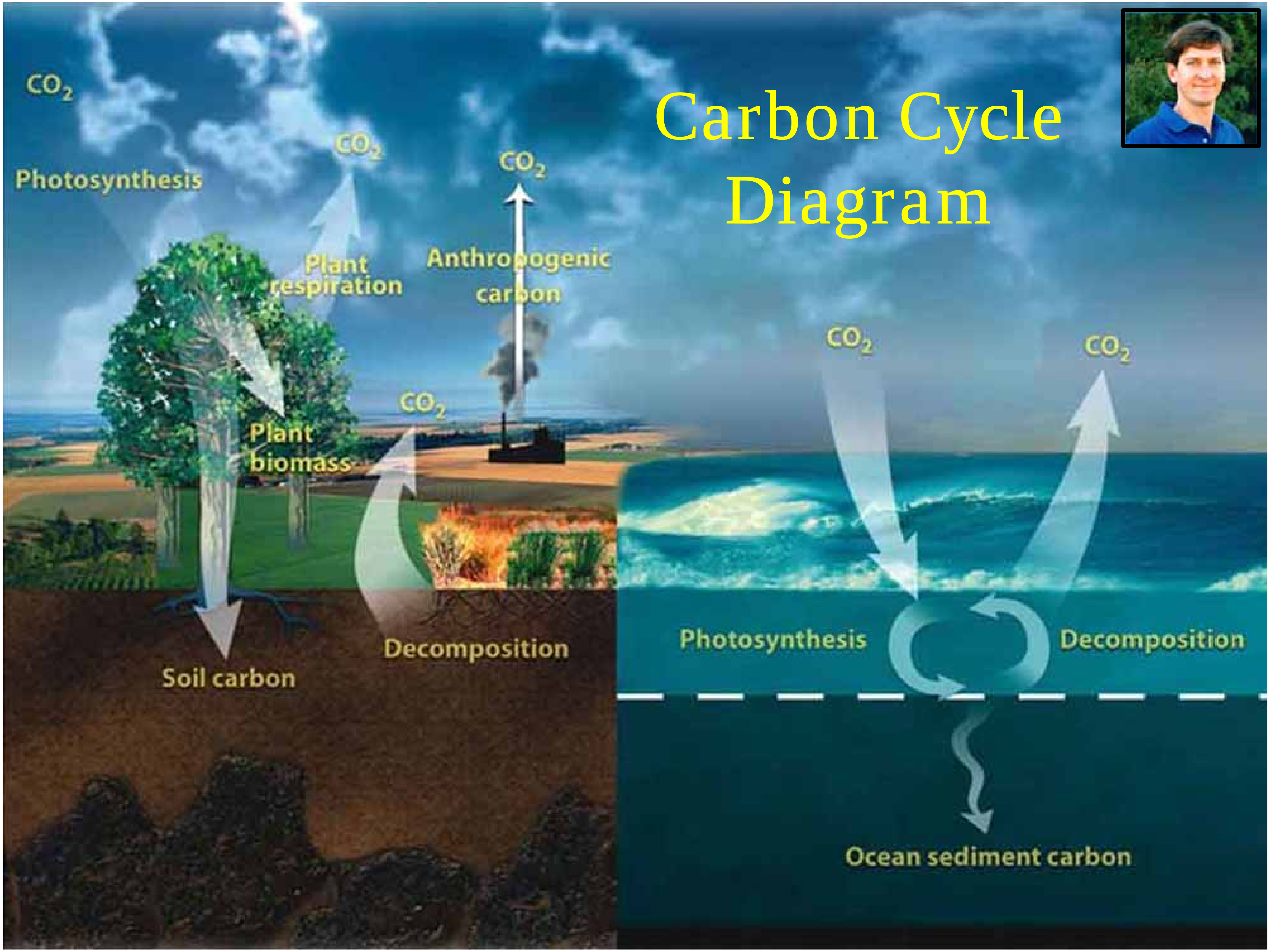

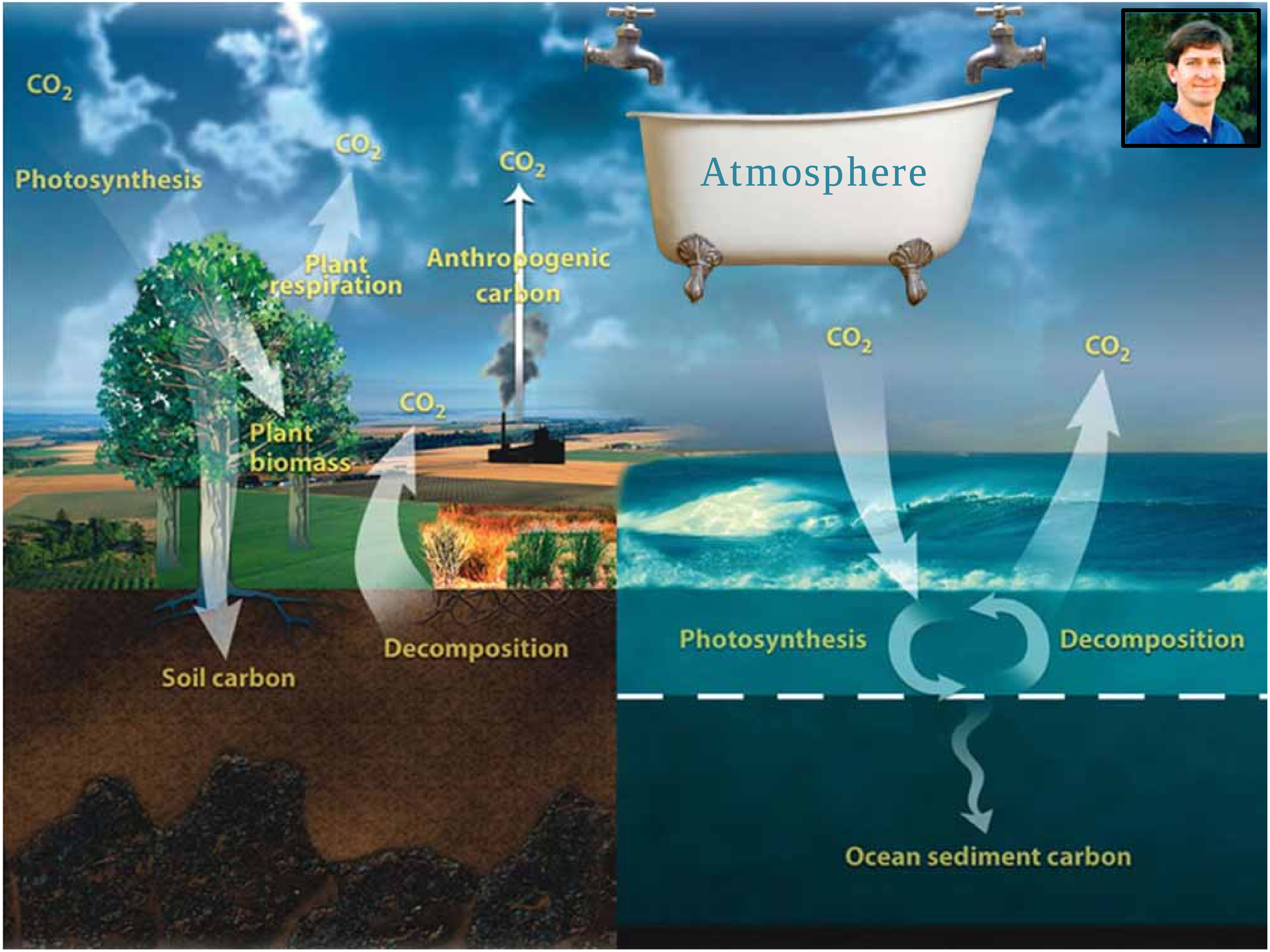

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Photosynthesis
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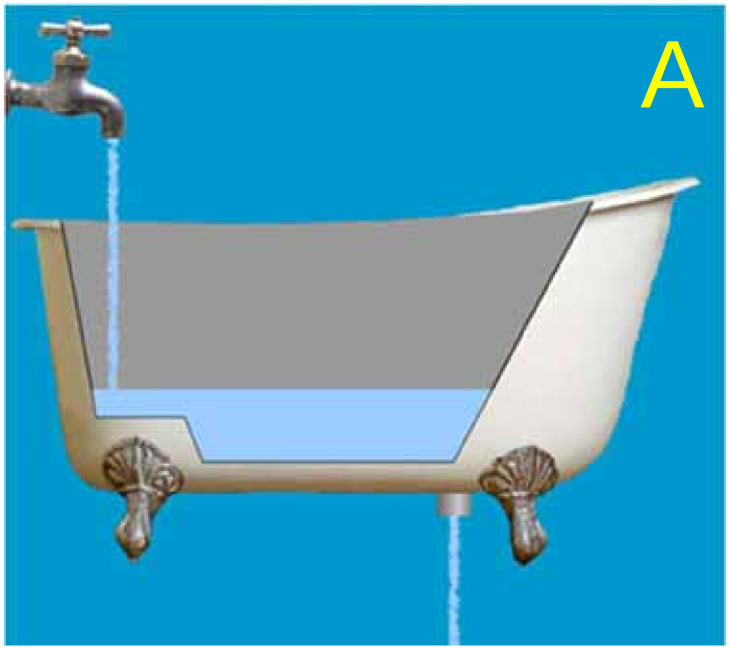
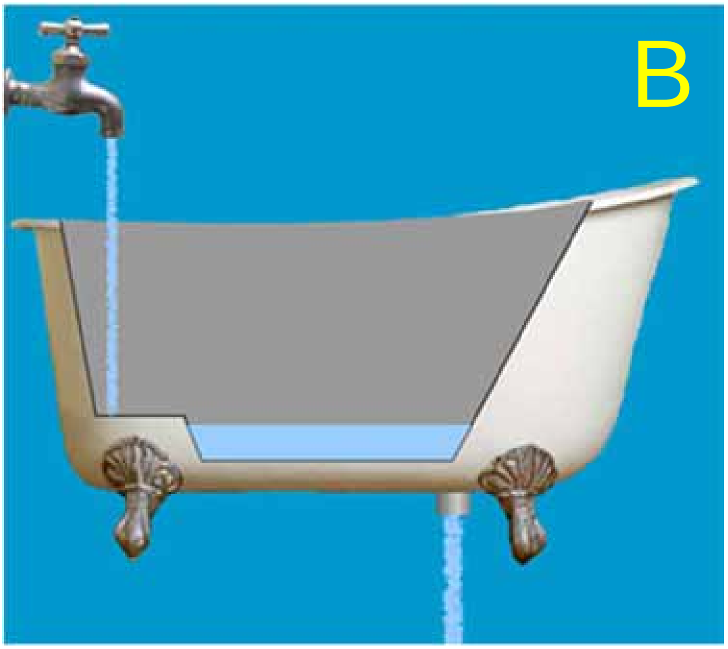
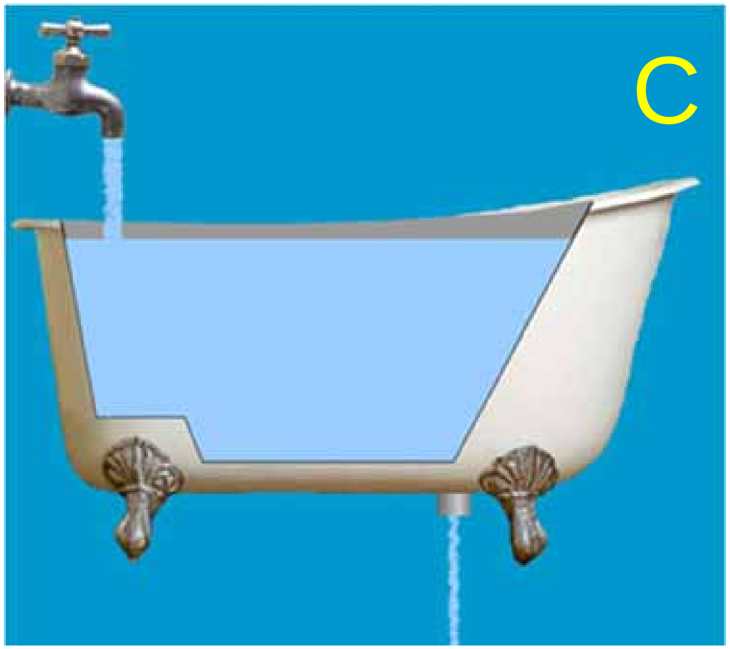
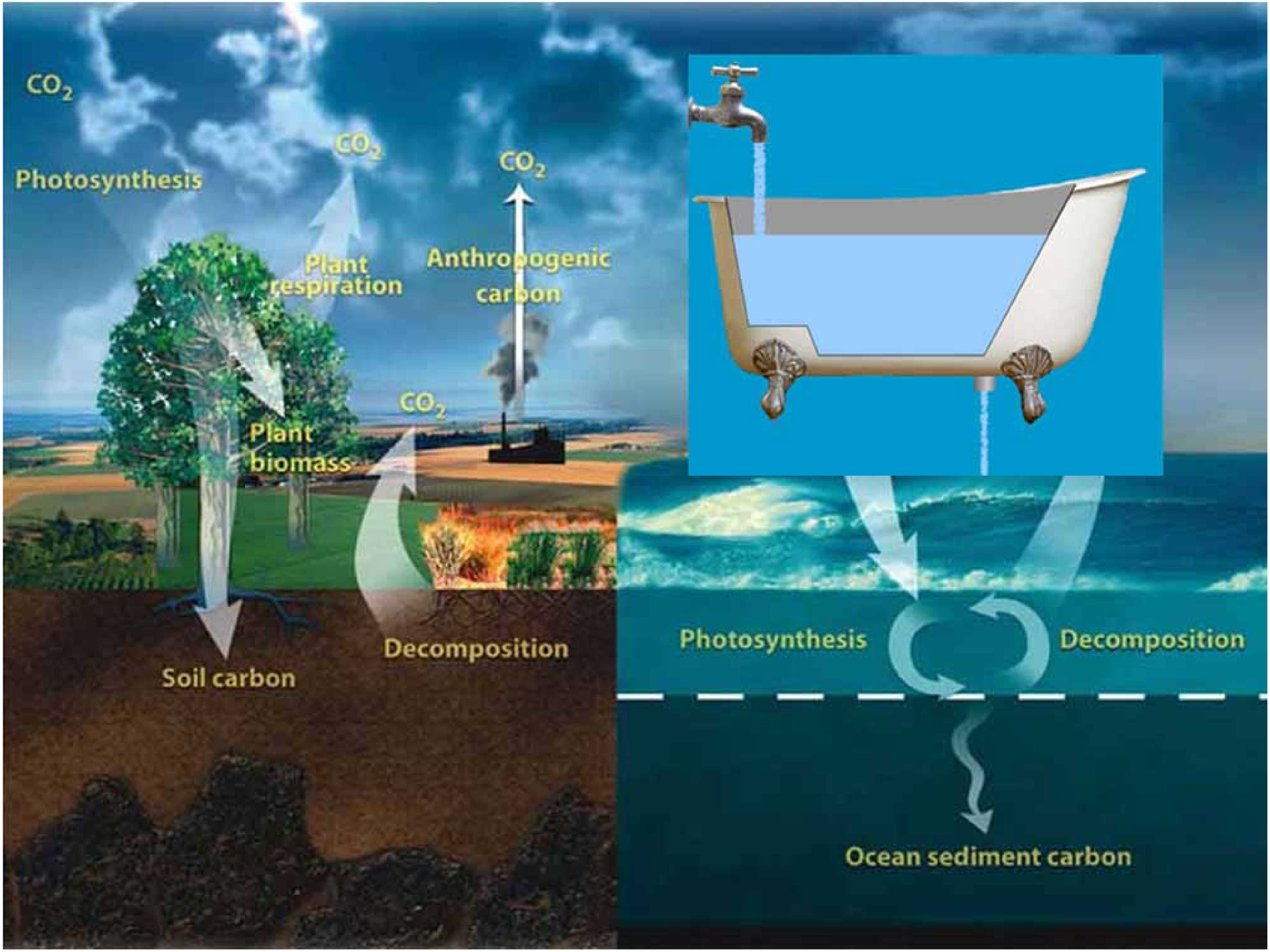
Fossil Fuel CO_2 Emissions









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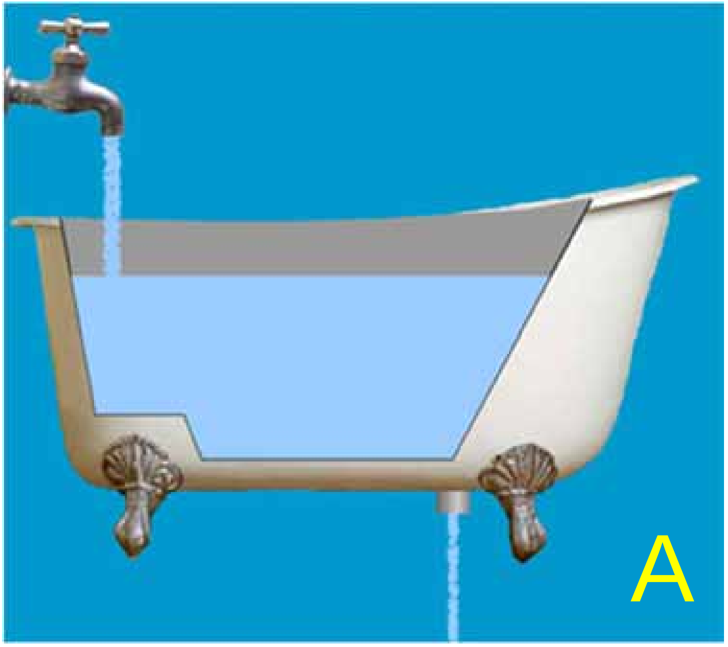
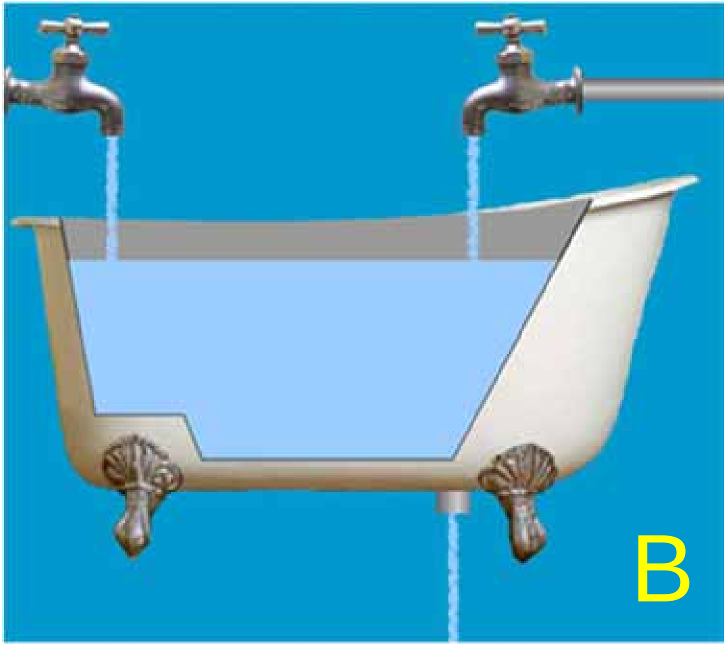
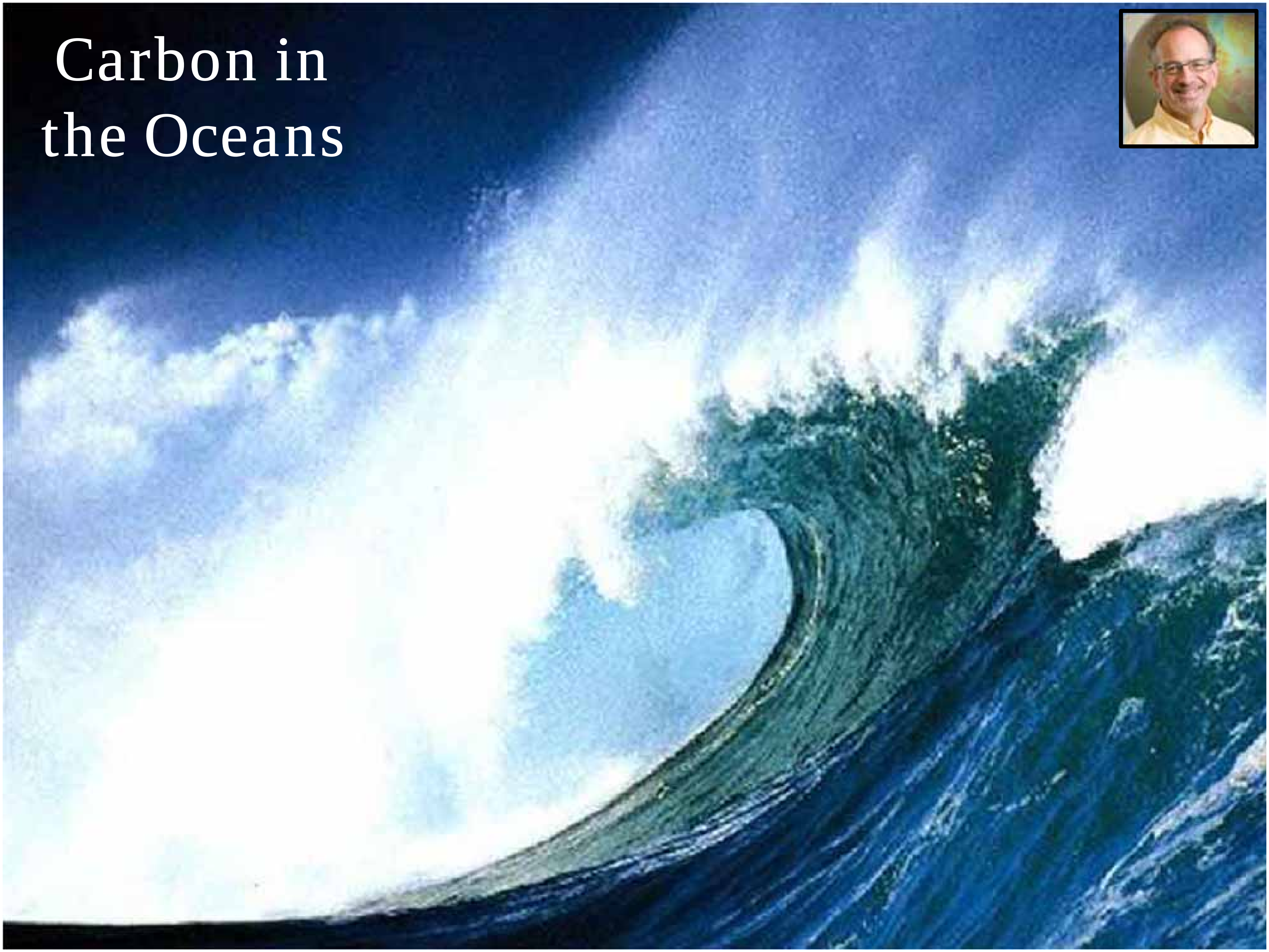
Which version of model is better for your students?

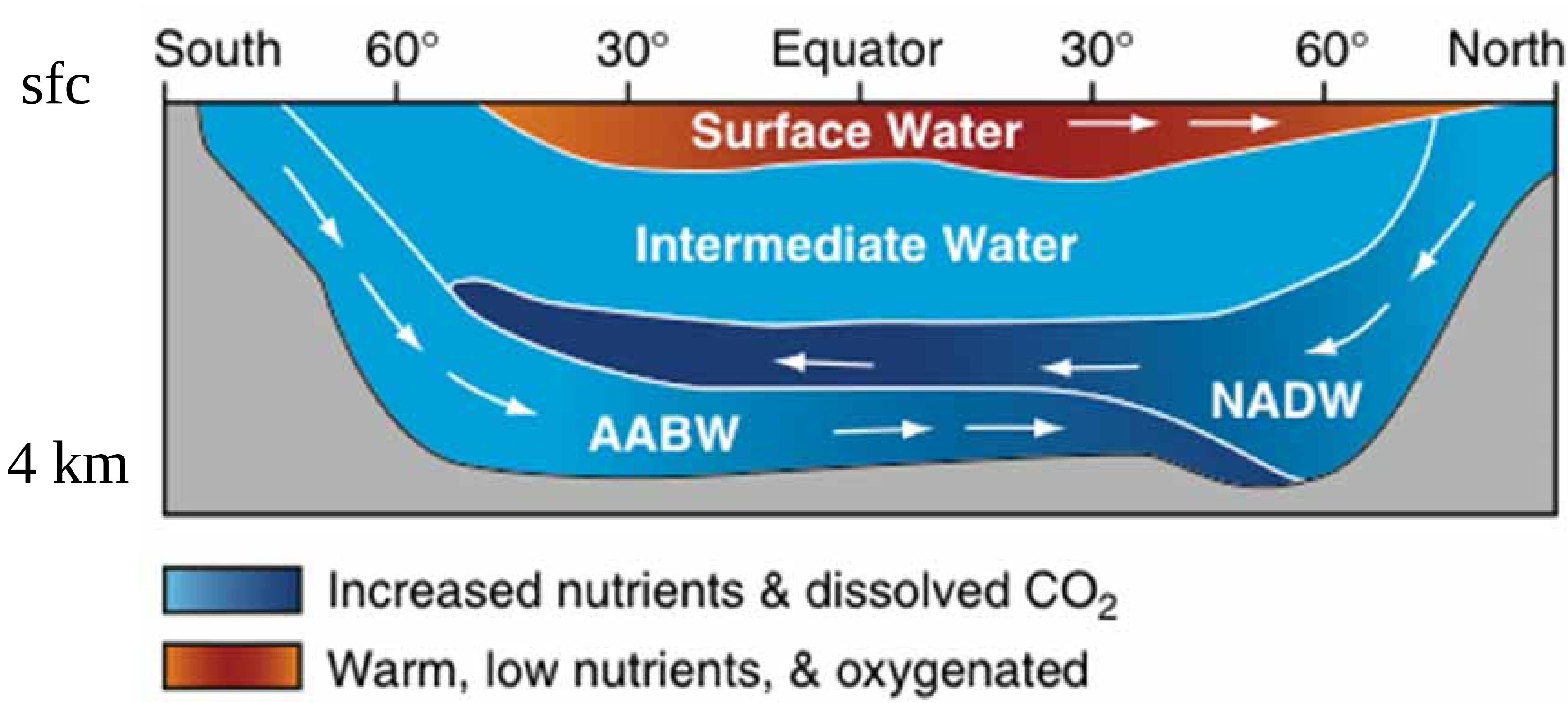




Carbon in the Oceans

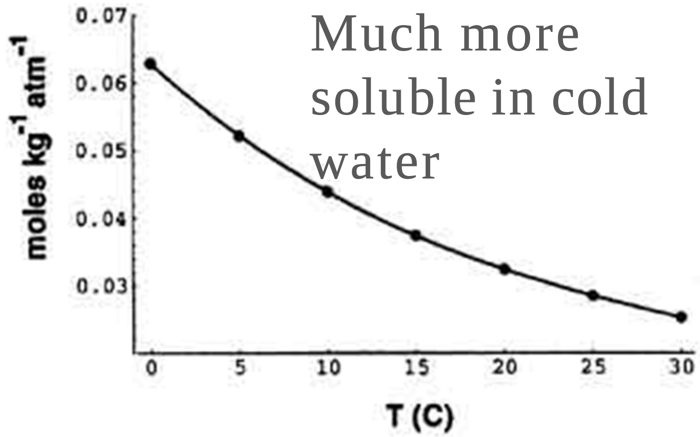


Layers of Water in the Oceans

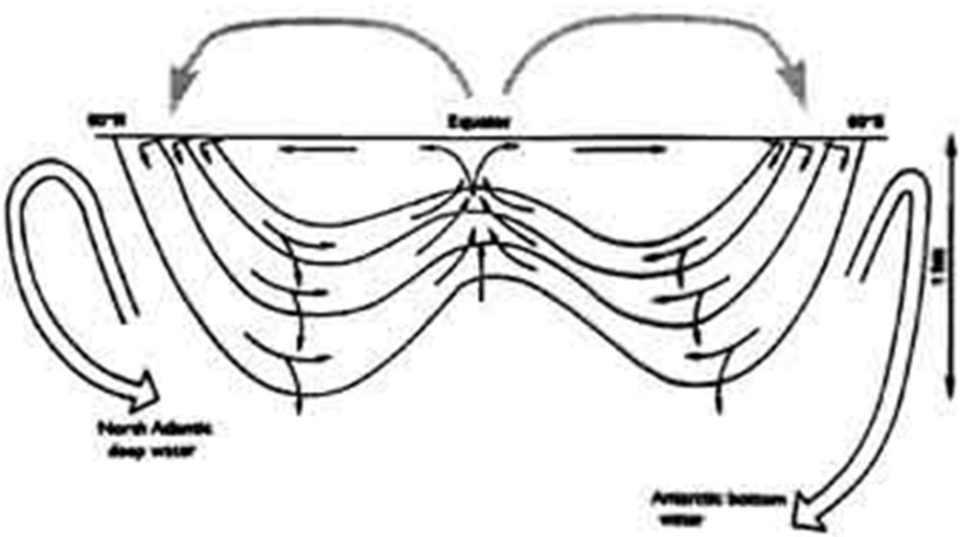


- Warm (buoyant) water floats on top of cold water
- Very cold water in polar winter sinks to the bottom
- Takes about 1000 years to circulate!

CO2 Dissolves in Seawater

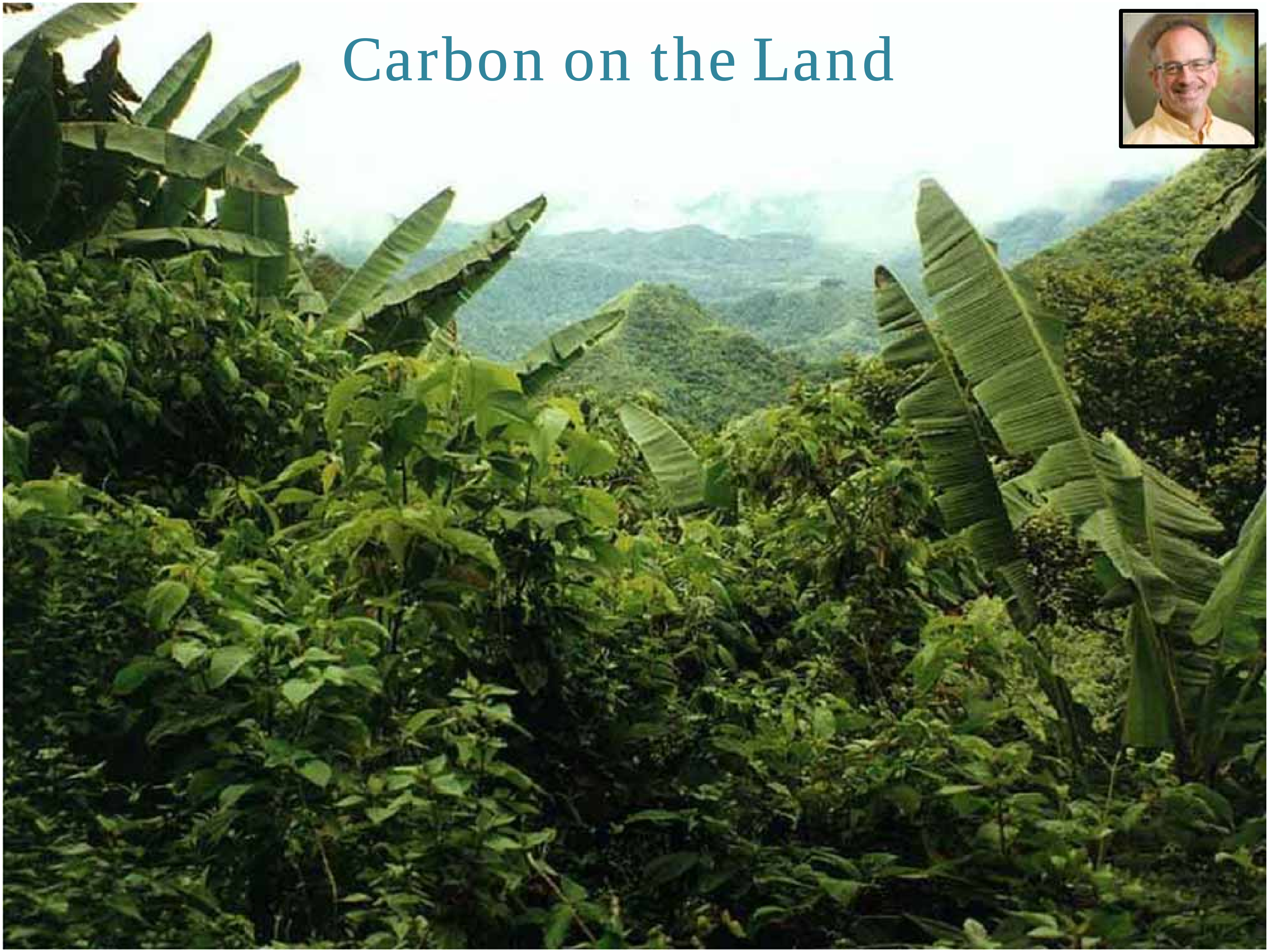


Much more soluble in cold water

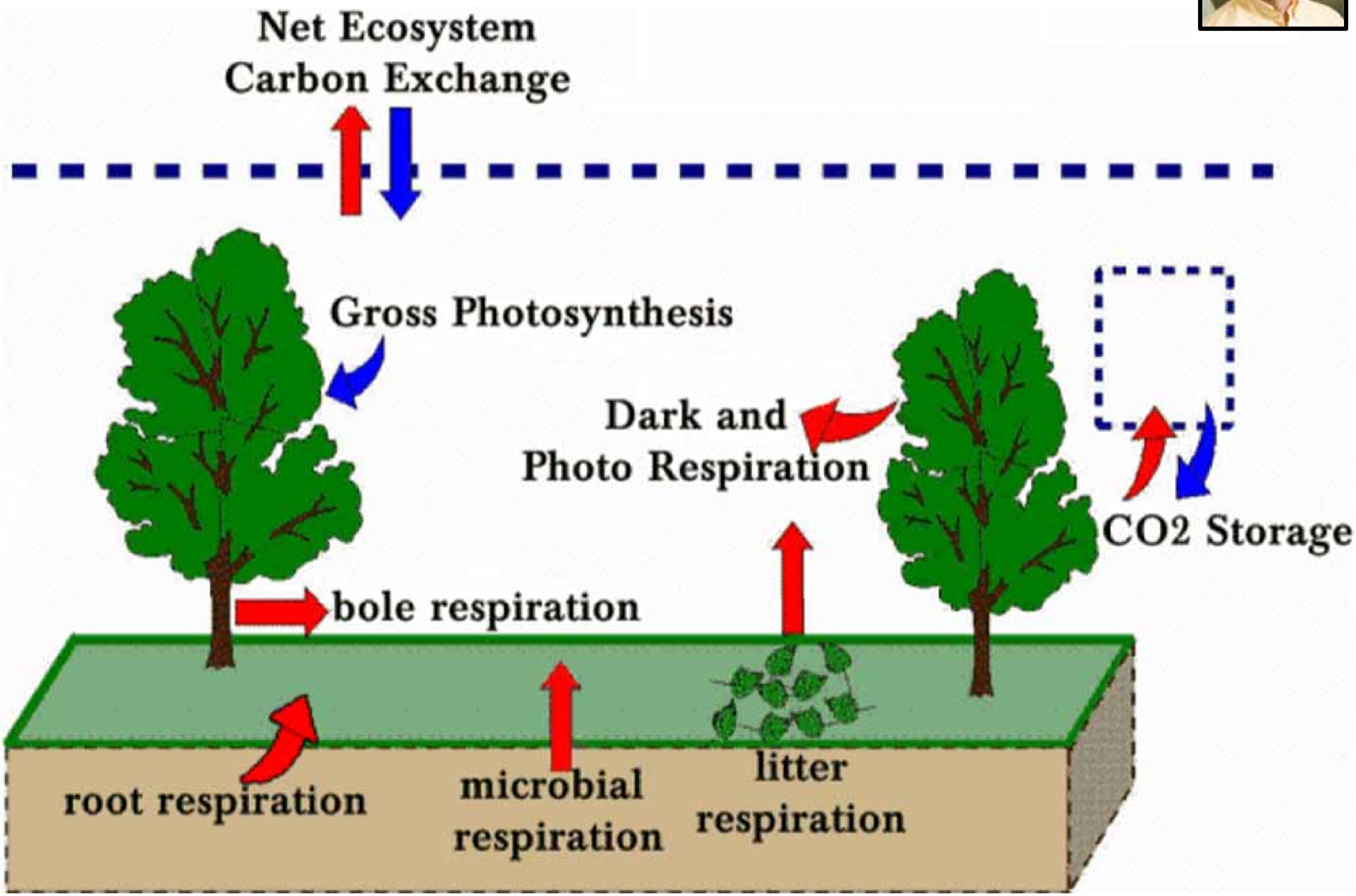


- Dissolves into cold polar water and sinks
- Travels along surfaces of constant temperature
- Upwelling and warming in tropical waters releases CO2 to the air
- Winds complete the loop

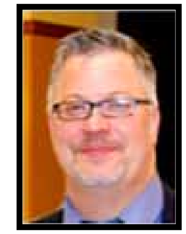
Carbon on the Land



Metabolism of Living Ecosystems

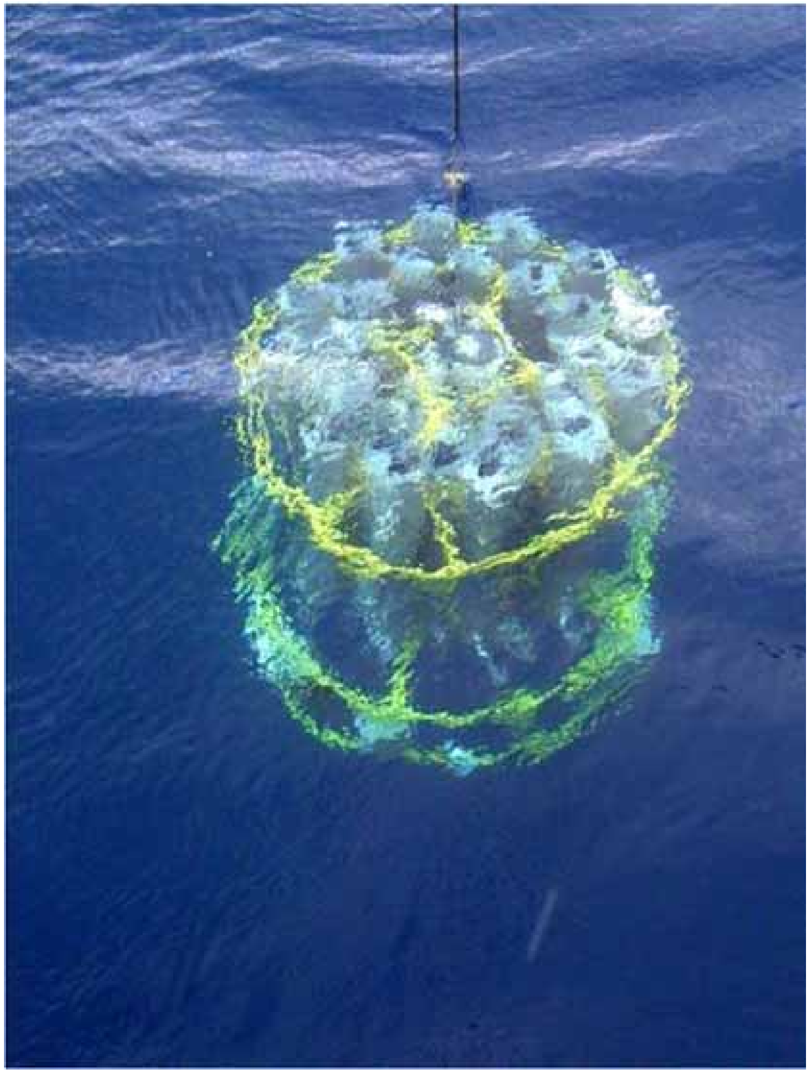


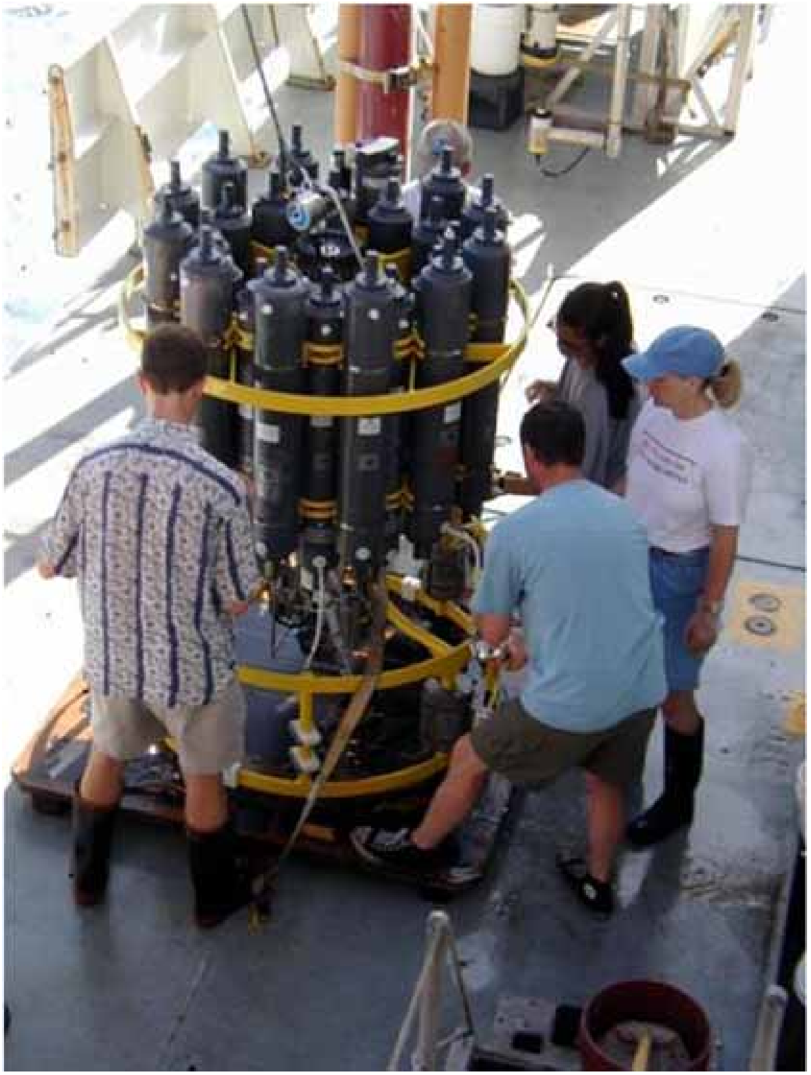




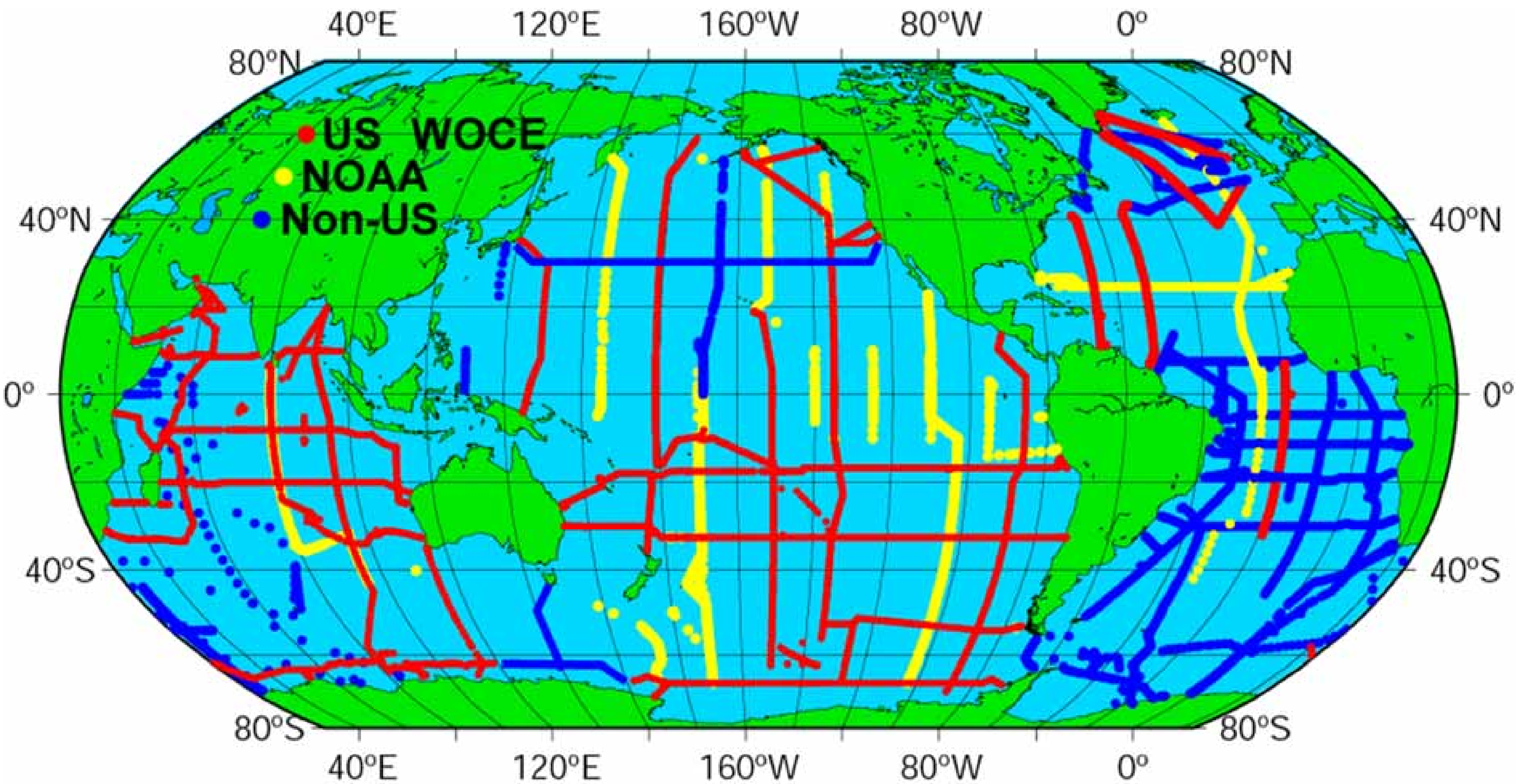
Questions?

Measuring Carbon in the Deep Sea





Sampling Carbon in the Deep Oceans



each dot is a profile to the bottom!

Fossil Carbon Dissolved in the Oceans

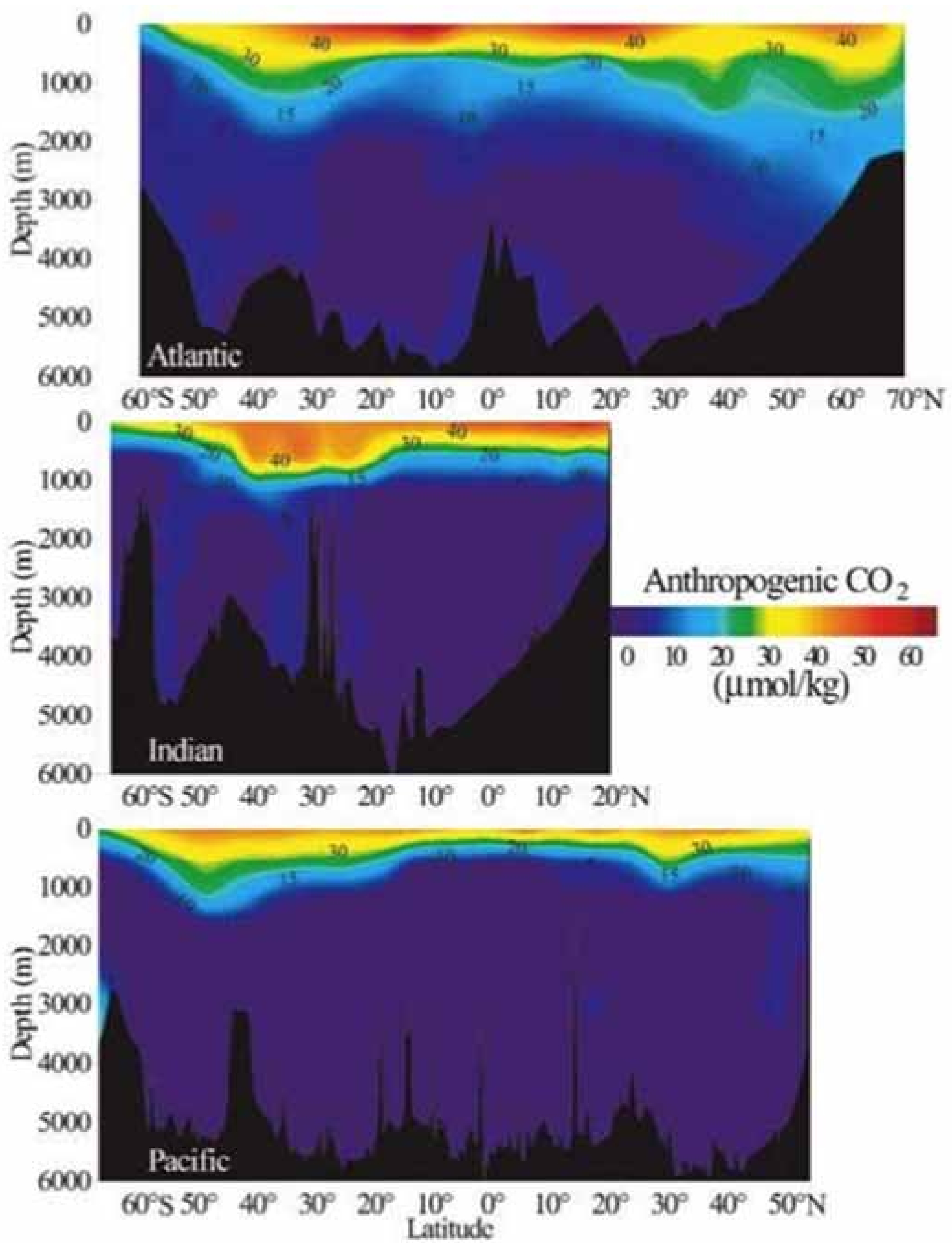
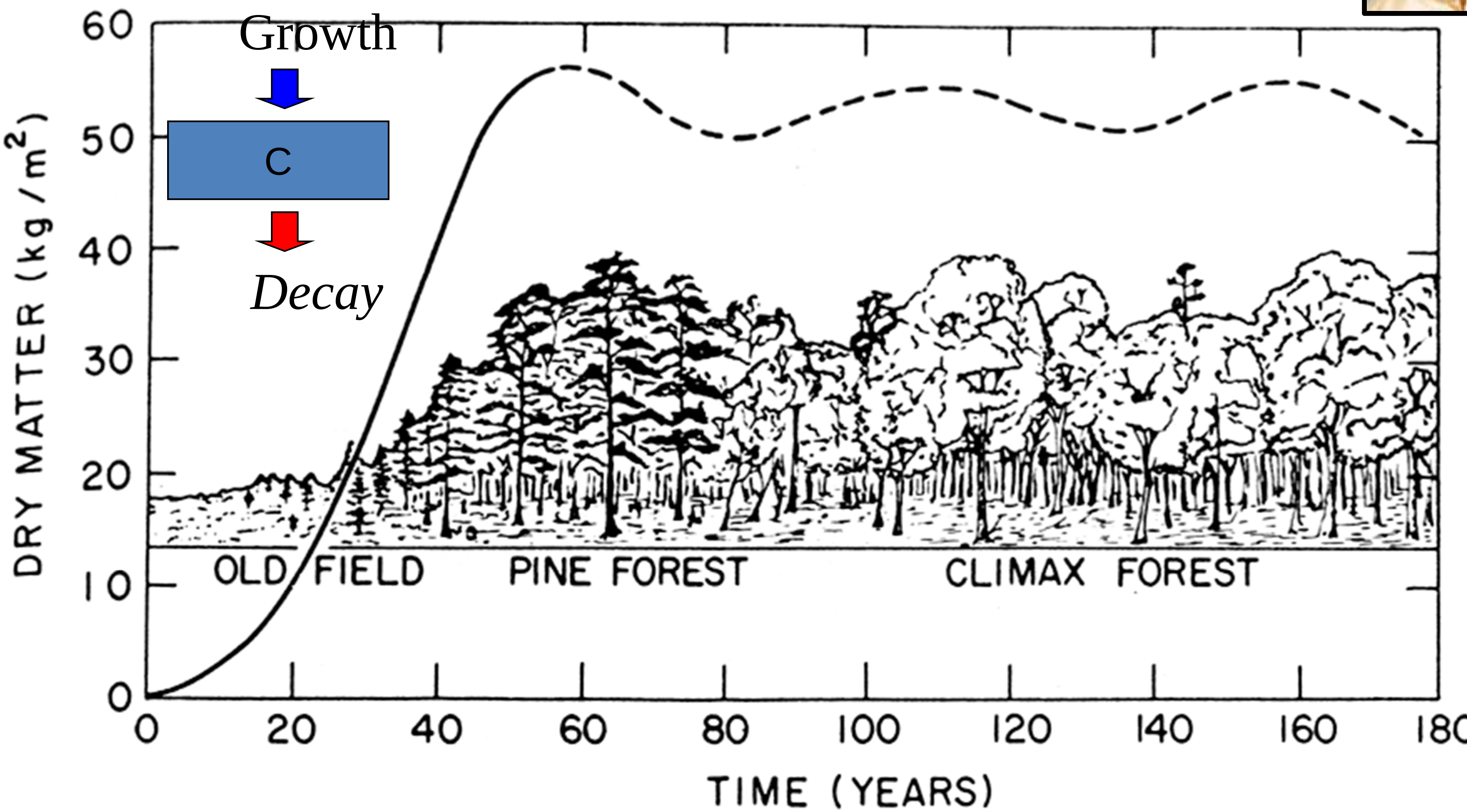


Figure 8. Zonal mean distributions of estimated anthropogenic CO_2 concentrations (in units of µmol kg^{-1}) along north-south transects in the Atlantic, Indian and Pacific oceans. The Pacific and Indian Ocean data are from the Global CO_2 Survey (this study), and the Atlantic Ocean data are from Gruber (1998).

- Nearly all the fossil CO_2 is confined near the surface
- Some fossil carbon has sunk to the bottom near the poles
- Most of the oceans “don’t know we’re here yet”

(Feeley et al, 2001)

Forest Disturbance and Succession



Woodwell and Whittaker, 1968

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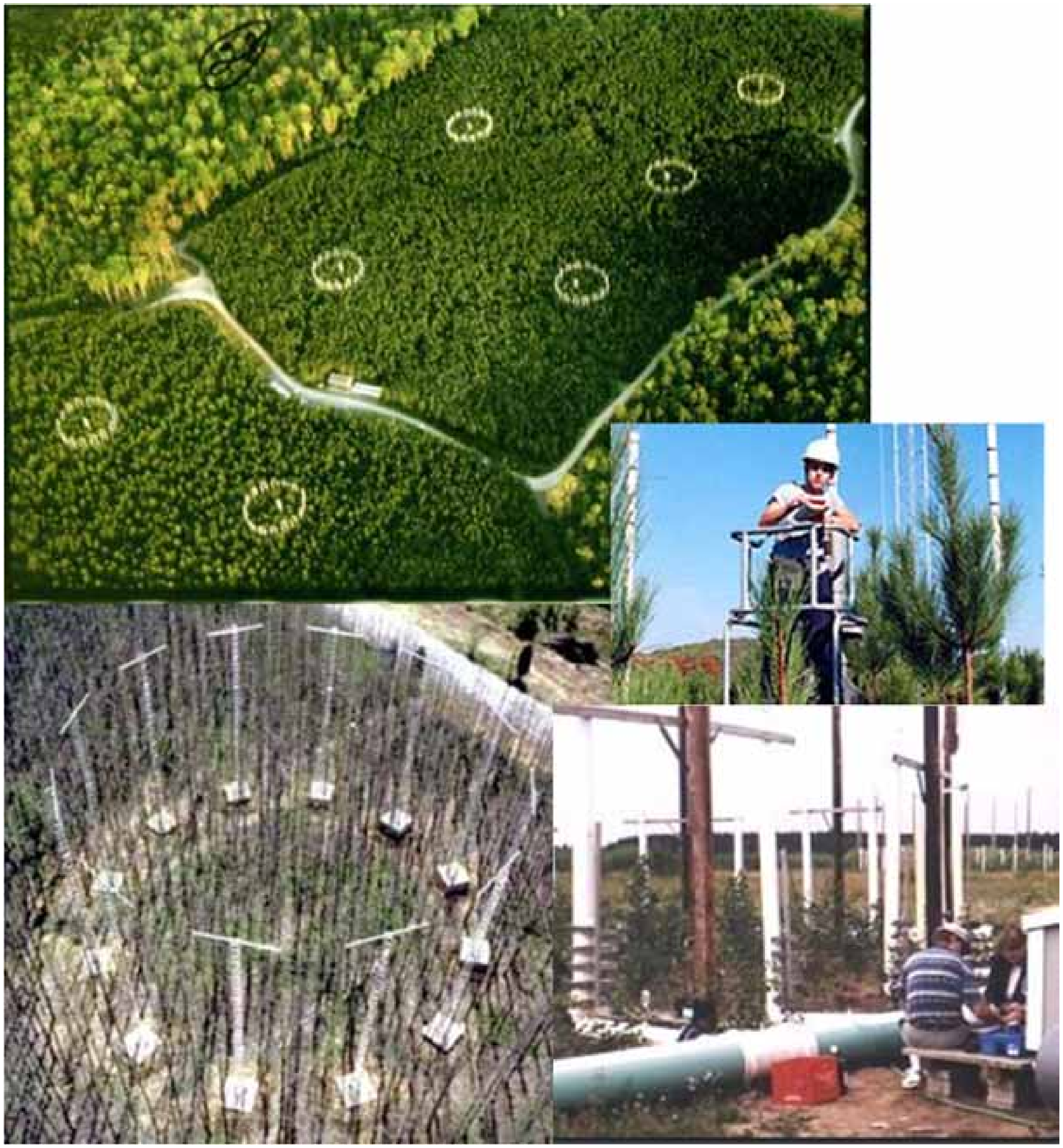
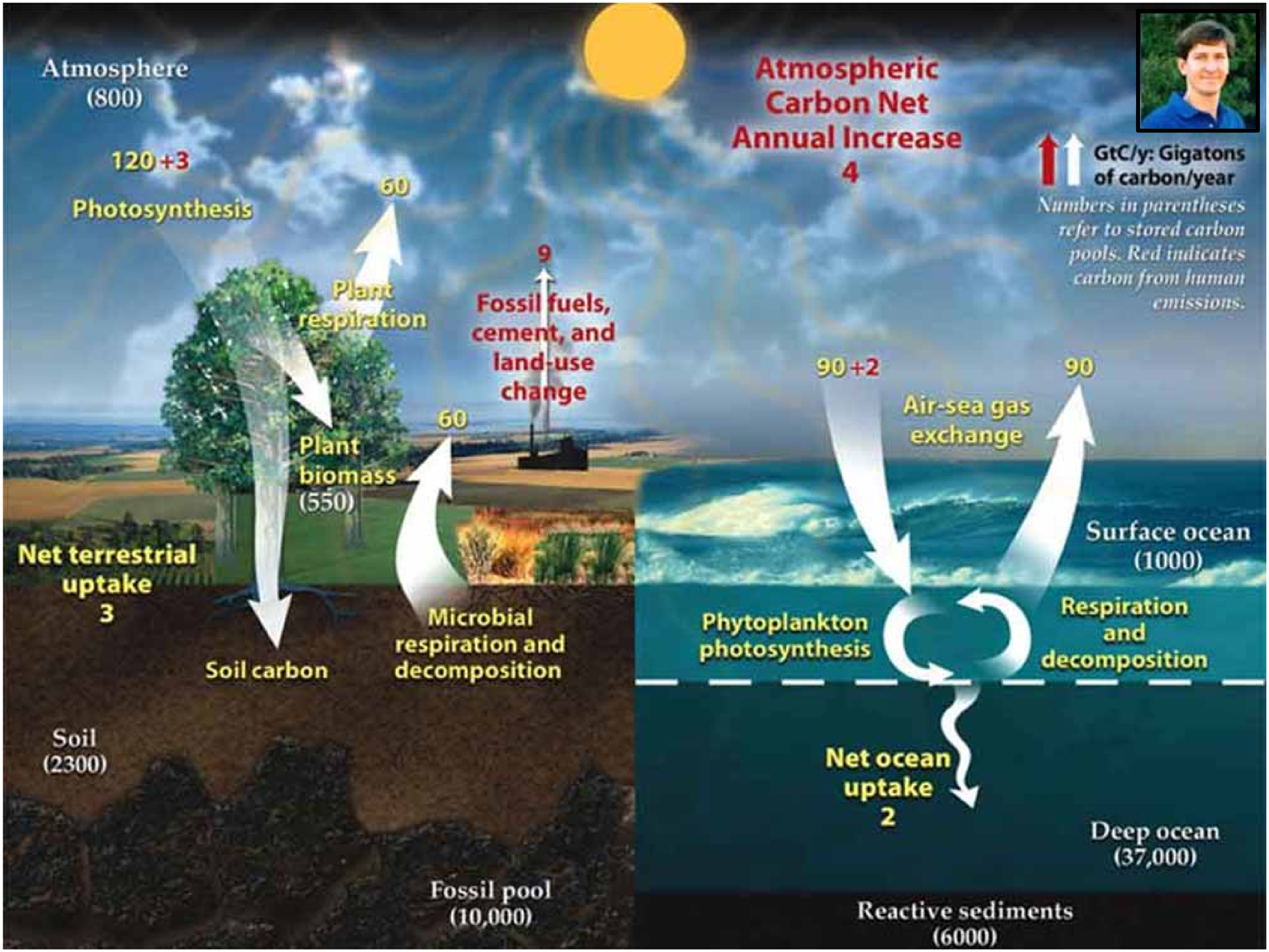
Forest Disturbance and Succession

CO2 Fertilization Enhances Growth




Atmosphere
(800)
120 +3
Photosynthesis
60
Plant
respiration
9
Fossil fuels,
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change
Atmospheric
Carbon Net
Annual Increase
4
GtC/y: Gigatons
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Numbers in parentheses
refer to stored carbon
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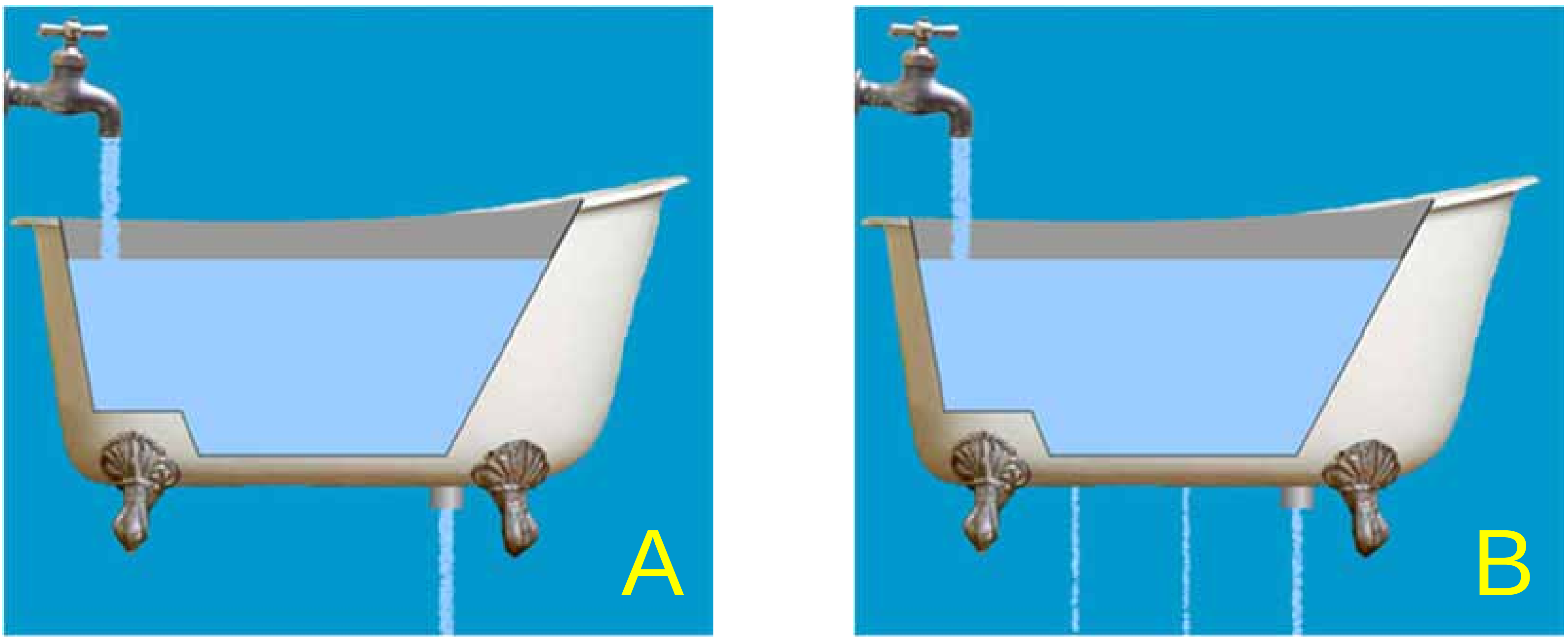
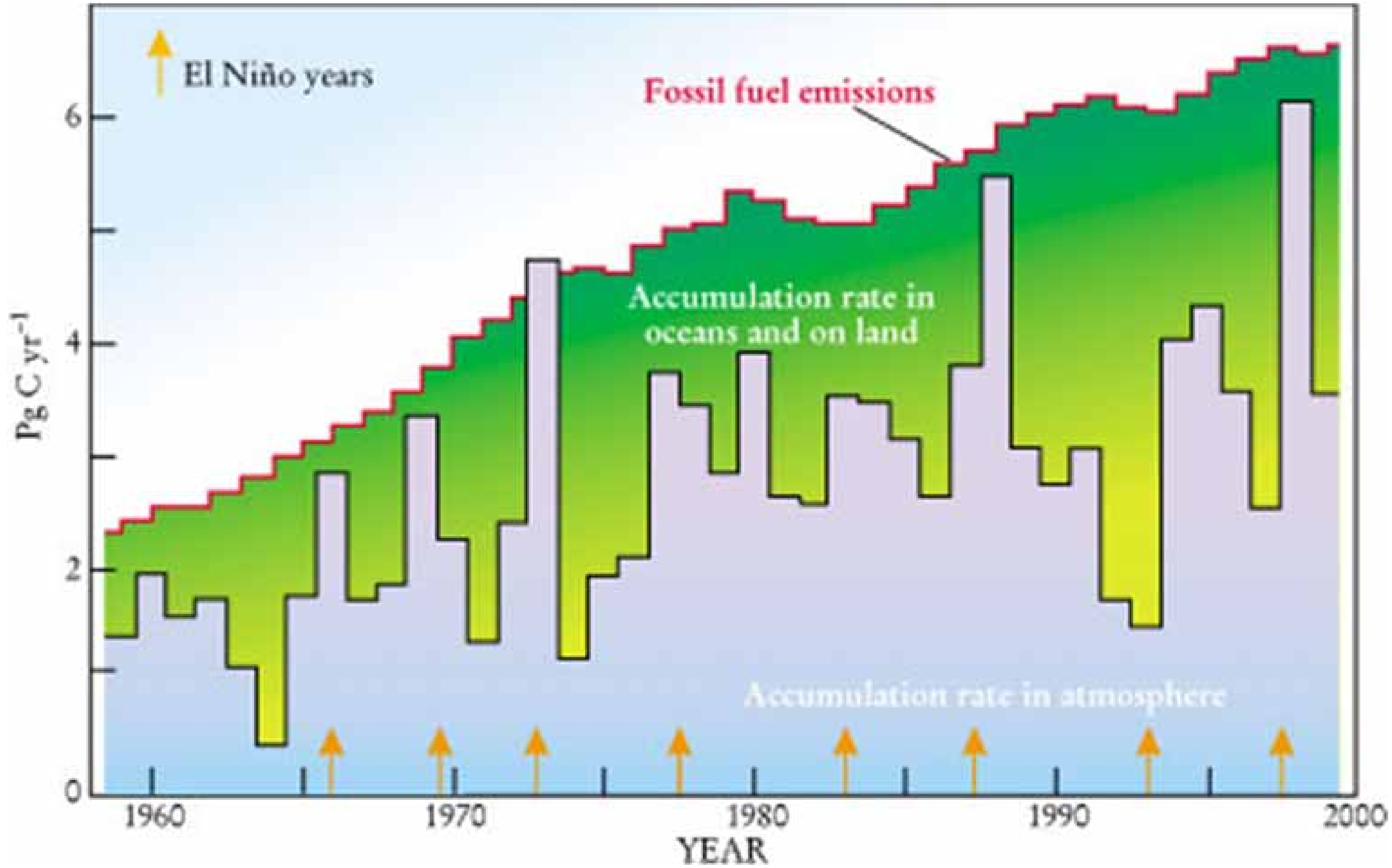
90 +2
90
Air-sea gas
exchange
Plant
biomass
(550)
60
Net terrestrial
uptake
3
Soil carbon
Microbial
respiration and
decomposition
Surface ocean
(1000)
Phytoplankton
photosynthesis
Respiration
and
decomposition
Net ocean
uptake
2
Soil
(2300)
Deep ocean
(37,000)
Fossil pool
(10,000)
Reactive sediments
(6000)

Oceans and Plants Absorb Some of the Human Emissions



Where Has All the Carbon Gone?



Half the CO_2 "goes away!"

- Some years almost all the fossil carbon goes into the atmosphere, some years almost none
- Year-to-year variability in sink activity is much greater than in fossil fuel emissions
- Sink strength is related to El Niño. Why? How?

Where Has All the Carbon Gone?

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  - Response to changing climate (e.g., Boreal warming)

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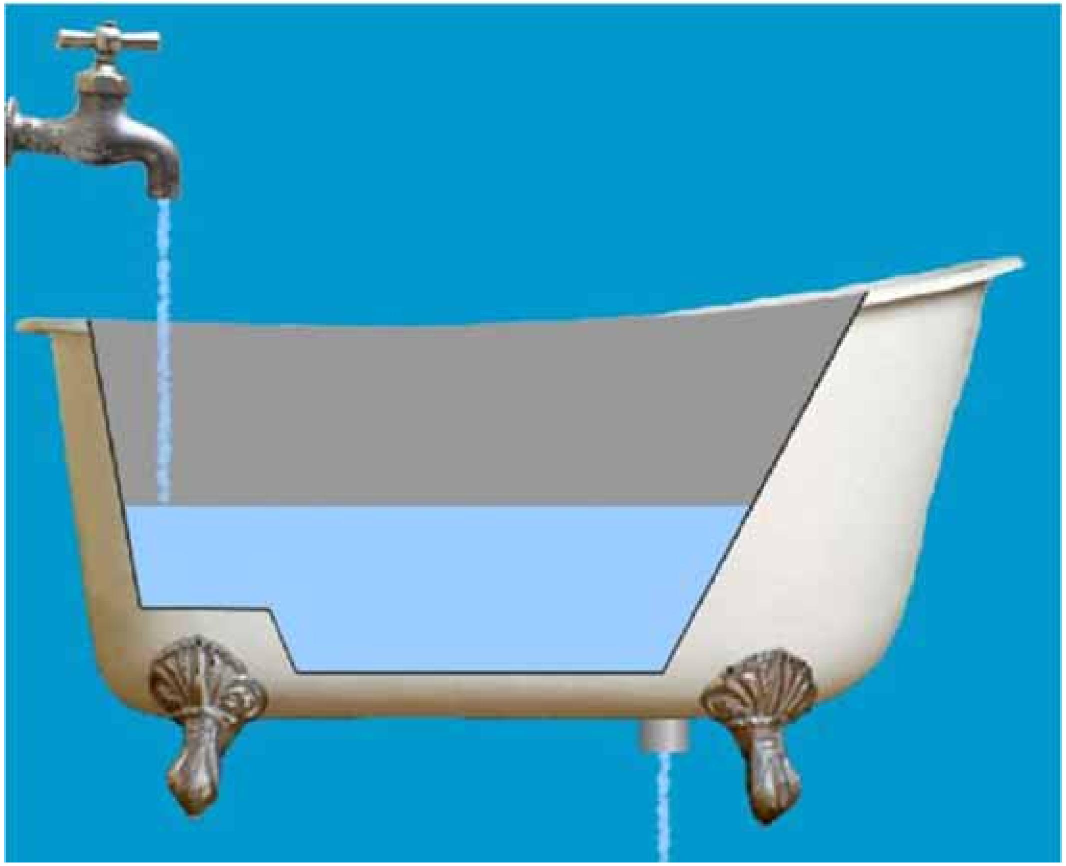
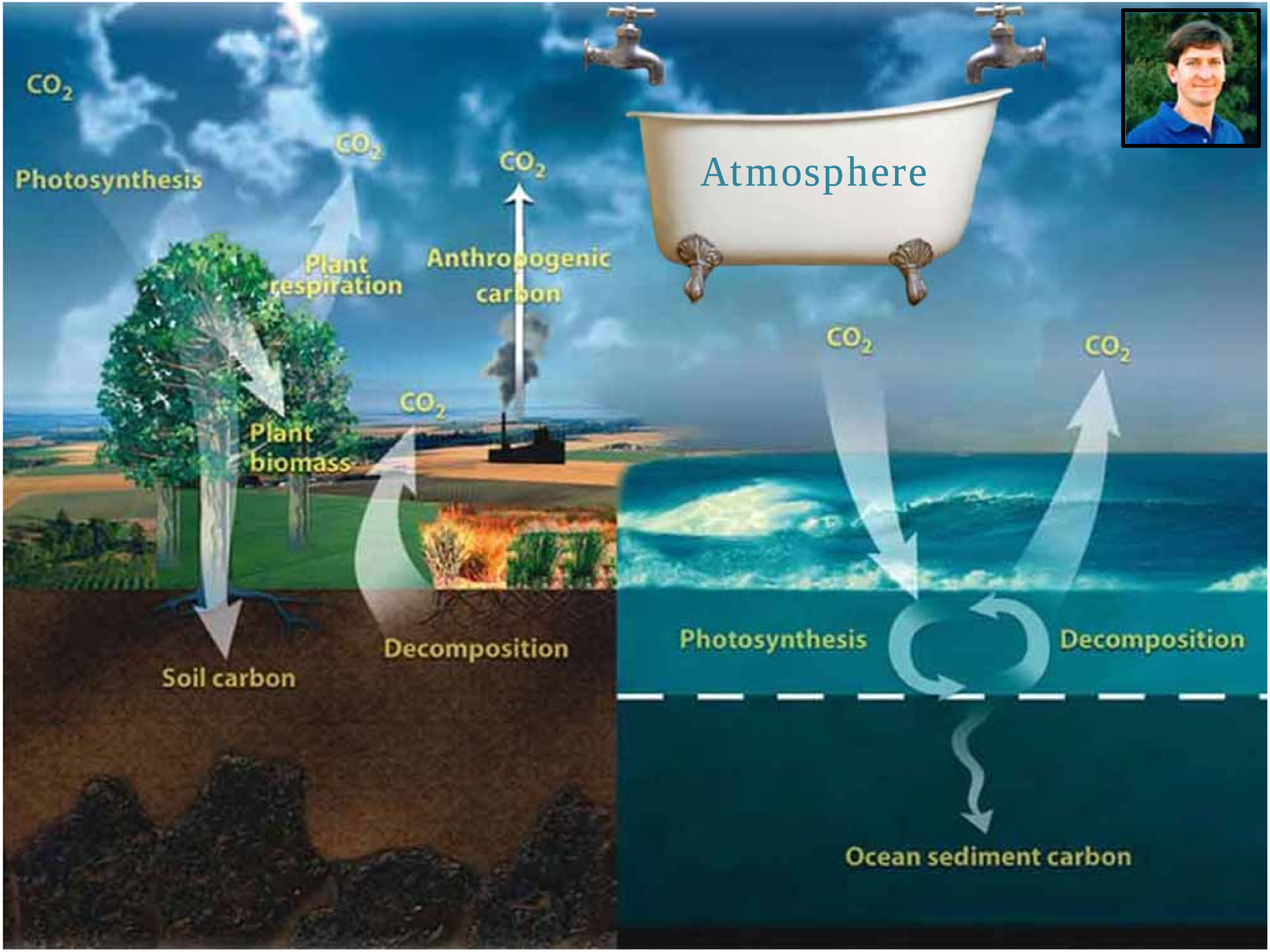
Where does inflow come from?
Where does outflow go to?

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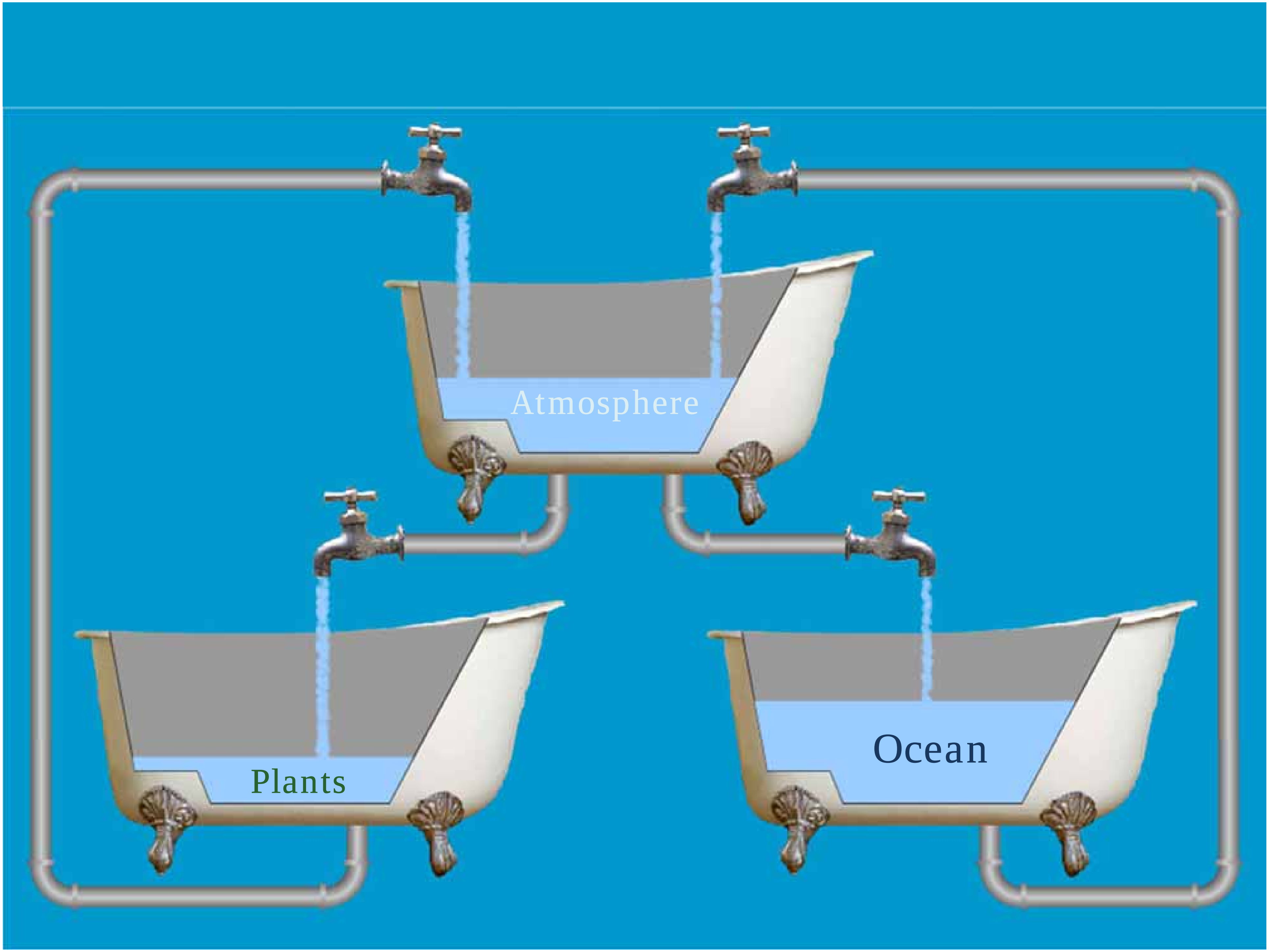
Atmosphere
Plants
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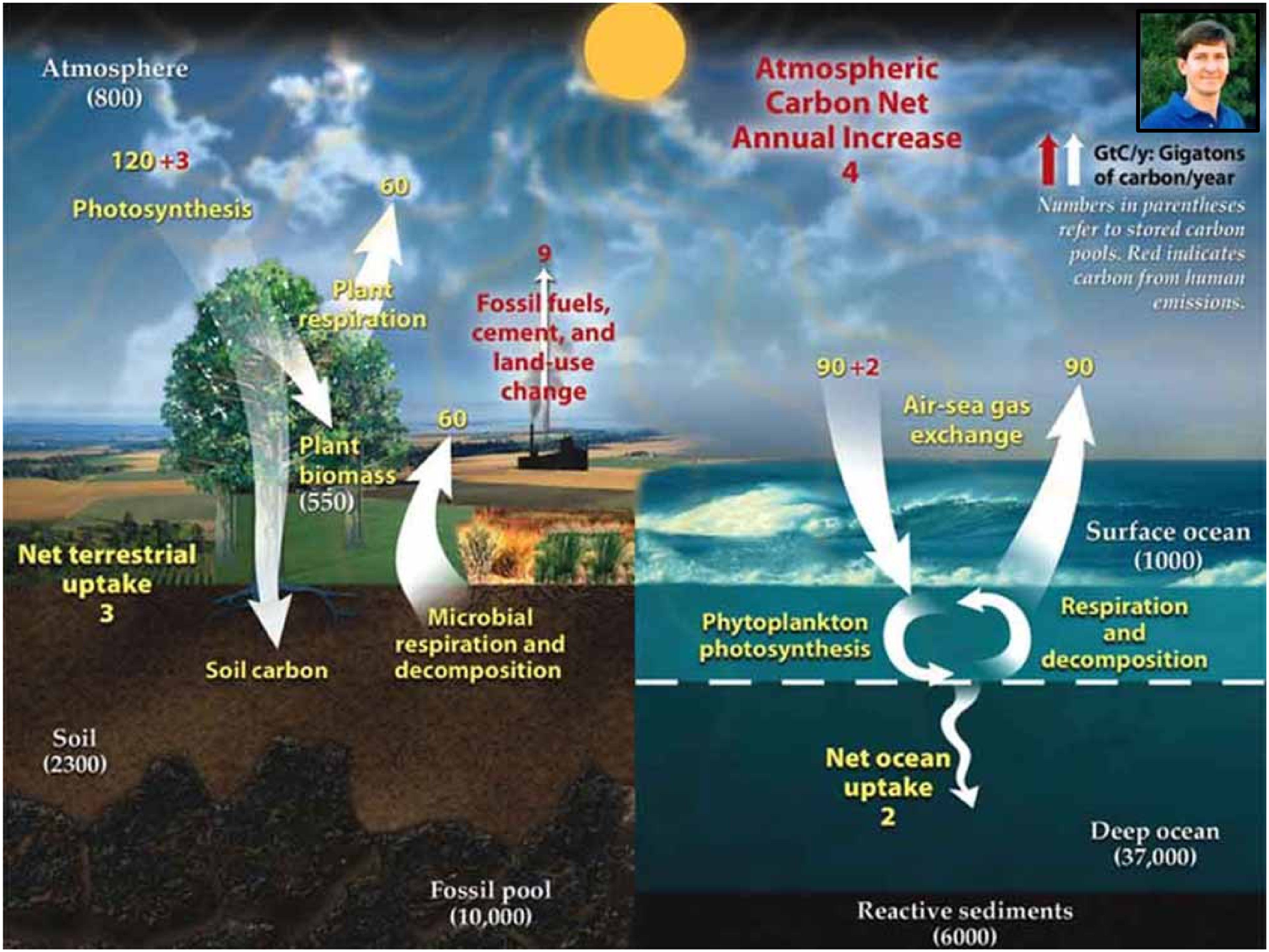
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Air-sea gas
exchange
Surface ocean
(1000)
Net terrestrial
uptake
3
Soil carbon
Microbial
respiration and
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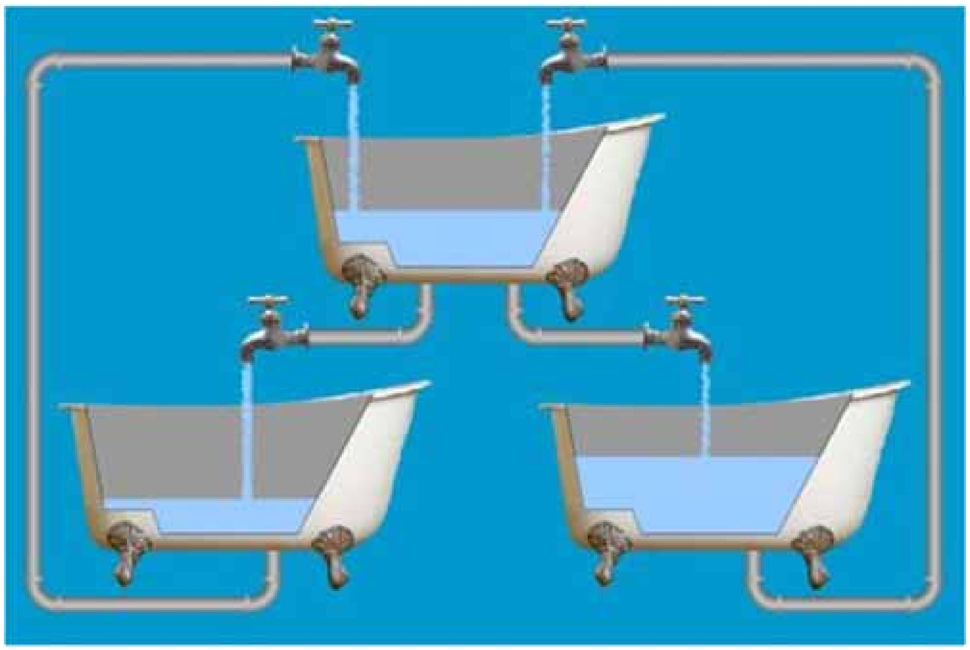
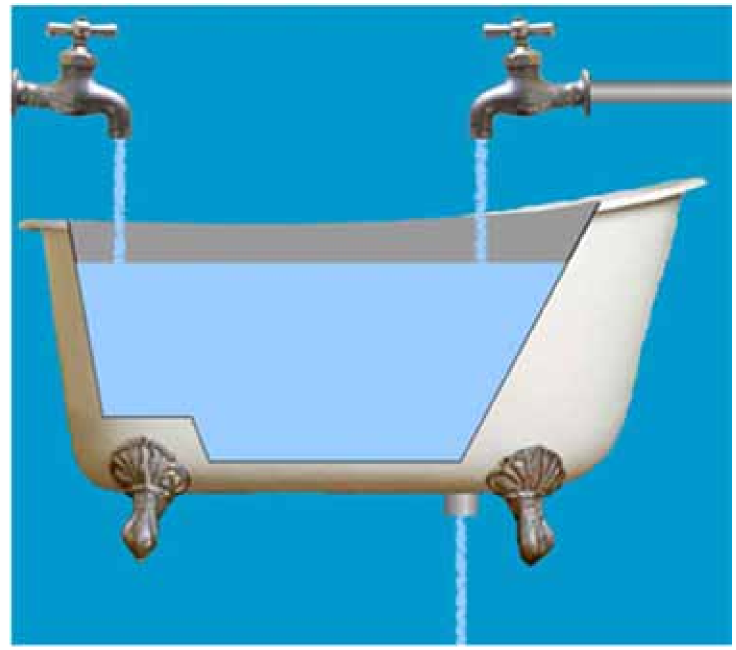
photosynthesis
Respiration
and
decomposition
Soil
(2300)
Net ocean
uptake
2
Deep ocean
(37,000)
Fossil pool
(10,000)
Reactive sediments
(6000)

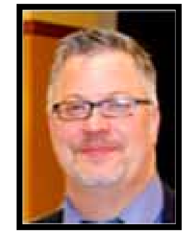
Animations online at:

spark.ucar.edu/workshops









Questions?

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