The Keeling plot charts

a) Global temperature vs. year.

b) Atmospheric methane concentration vs. year

c) Atmospheric carbon dioxide concentration vs. year

d) Global temperature vs atmospheric carbon dioxide concentration

e) Global temperature vs atmospheric methane concentration.
The term “climate forcing” refers to
a) the removal time of carbon dioxide from the Earth’s atmosphere
b) the temperature change caused by greenhouse gases
c) the introduction of sulfate aerosols into the Earth’s atmosphere to enhance cloud formation
d) the seeding of the oceans with minerals to encourage plankton growth to transfer carbon dioxide from the atmosphere to the ocean depths
e) the construction of a giant sunshade in space to reduce the Earth’s average temperature
Announcements

• Homework 2 will be posted today, due Monday 3/9 at 3:20PM
• Exam 1: 3/11
• More reading quiz questions next time.
Content

• Carbon Cycle:
  ➢ Reservoirs
  ➢ Fluxes
  ➢ Resident Times
• The sum of all bond dipole vectors in a molecule is the molecular dipole moment.

• When a molecule absorbs an amount of energy and vibrates, it has gone from its ground state to a vibrational excited state.

• Vibrational Energy Levels are Quantized.

\[ E = h \frac{c}{\lambda} \]

\( E \) — Energy
\( h \) — Plank's Constant
\( c \) — Speed of light in vacuum
\( \lambda \) — Wavelength

• Vibrational modes in which the dipole moment is altered are heat absorbing. These are most important for climate.
The series of processes by which carbon compounds are interconverted in the environment.
Reservoirs, Fluxes, and Resident Time

• **Reservoirs** are pools of carbon that can be uniquely defined.

• The rate of movement of carbon from one reservoir to another is the **Flux**.

• **Resident Time** is the average time that carbon spends in any given reservoir.
## Fluxes
(In Billions of Metric Tons per Year)

### Land Plants
- Photosynthesis: 120
- Plant respiration: 60
- Soil respiration: 60
- Plants to soils: 60
- Fossil fuel formation: 0.0001
- Fossil fuel burning: 6
- Deforestation: 2
Fluxes
(In Billions of Metric Tons per Year)

• Oceans
  - Dissolving from atmosphere  107
  - Exsolving to atmosphere  105
  - Carbonate formation  0.3
  - Weathering  0.6

• Volcanoes
  - Volcano activity  0.1
Seasonal vs. Annual

• Large fluxes are seasonal

• **Land:** photosynthesis and respiration
  (~120 bT/yr each way).

• **Ocean:** dissolving and exsolving
  (~110 bT/yr each way)

• Over a year period most of the time these are in balance.

• Slightly out of balance now due to fossil fuel inputs

The big fluxes on a year-to-year basis are due to fossil fuel burning and deforestation.
Observation:

- The flux of carbon OUT OF fossil fuel is 60,000 times greater than the flux of carbon INTO fossil fuels.

Land Plants

- Photosynthesis: 120
- Plant respiration: 60
- Soil respiration: 60
- Plants to soils: 60
- Fossil fuel formation: 0.0001
- Fossil fuel burning: 6
- Deforestation: 2
### Reservoirs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Billions of Metric Tons (GT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>720</td>
</tr>
<tr>
<td>Ocean</td>
<td>39,000</td>
</tr>
<tr>
<td>Carbonates</td>
<td>100,000,000</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>4,000</td>
</tr>
<tr>
<td>Land plants</td>
<td>560</td>
</tr>
<tr>
<td>Soils</td>
<td>1500</td>
</tr>
</tbody>
</table>

What observations can we make about where the carbon is (is not)?
Observations contd.

- Flux of carbon OUT OF fossil fuel is 60,000 times faster than the flux of carbon INTO fossil fuels.
- Most carbon is in rocks such as carbonates and other sediments.
- Most of the carbon that is not in rocks is in the ocean.
- There is about 3 times more carbon in soils than in land plants.
Resident Times

- Land Plants ~ 5 yr
- Atmosphere ~ 3 yr
- Soils ~ 25 yr
- Fossil fuels ~ 650 yr
- Oceans ~ 350 yr
- Carbonates ~ 150 Myr
Observations on Resident Times

• Because some in/out fluxes are not balanced (e.g. atmosphere and fossil fuels) the resident times will be different.

• For the same reason reservoirs will grow or shrink.

• Our atmosphere mixes in about one year so the normal resident time of carbon in the air is long enough that it is well mixed.

What does this mean...?

- Our $CO_2$ is everyone's problem and vice-versa.
Observations on Resident Times

• Reservoirs are interconnected
  ➢ Short resident times are underestimates.
  ➢ Cleaning up $CO_2$ directly from the atmosphere:
    ❑ Reservoirs with longer resident time (e.g. the ocean) will put carbon back into the atmosphere.

Taking all observations into account, the atmospheric resident time could be closer to 100 years!
The Carbon Cycle
IClicker Question

The rate of movement of carbon from one reservoir to another is the

a) Reservoir
b) Resident Time
[c] Flux
d) None of the above
In Class Activity

• One gallon of fuel causes approximately 20 lb. of $CO_2$ emissions.

• 1 kg = 2.2 lb.

• 1 metric ton (T) = 1000 kg

• Coal energy density (24 MJ/kg)