Future of ocean carbon sink -- Sarmiento Group + GFDL
(1a) New model-based estimates of ocean carbon sink size confirm previous estimates.
(2a) A new state-of-the-art climate model has been completed and is running initial simulations.

Future of terrestrial carbon sink & Impacts of renewable energy -- Pacala Group + GFDL
(2b) A new state-of-the-art climate model with an interactive land model has been completed and is running initial simulations.
(3) Analysis of Wisconsin forests since the 1960’s indicate growth rates have decreased with rising CO2 levels, undermining the theory that carbon dioxide’s fertilizing effect on land plants would increase CO2 uptake in the future.

Present carbon sinks - observational constraints -- Bender Group
(1b) New observational-based estimates of terrestrial and ocean carbon sink size and variability confirm previous estimates.

Past carbon sinks -- Sigman Group
(4) New data indicate that polar oceans were stratified during the last glacial period, supporting the hypothesis that decreased evasion of CO2 from the deep ocean had a cooling influence on climate.
(5) Data from polar oceans provide the first evidence that natural iron variations produce changes in marine biological productivity, possibly influencing CO2 uptake.
### New observational & model based estimates of carbon sinks

**Carbon Sources and Sinks (Pg C yr⁻¹)⁹**

<table>
<thead>
<tr>
<th></th>
<th>1980's</th>
<th>1990's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuel Emissions</td>
<td>+5.4 ± 0.3</td>
<td>+6.3 ± 0.4</td>
</tr>
<tr>
<td>Atmospheric Increase</td>
<td>−3.3 ± 0.1</td>
<td>−3.2 ± 0.1</td>
</tr>
<tr>
<td>NET Oceans &amp; Land</td>
<td>−2.1 ± 0.3</td>
<td>−3.1 ± 0.4</td>
</tr>
</tbody>
</table>

⁹Based on IPCC (Prentice et al., 2001)

<table>
<thead>
<tr>
<th></th>
<th>Bender group (observations)</th>
<th>Sarmiento group (models)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Sink</td>
<td>−1.8 ± 0.6</td>
<td>−1.9 ± 0.2</td>
<td>−2.2 ± 0.5</td>
</tr>
<tr>
<td>Net Land Sink</td>
<td>−0.3 ± 0.7</td>
<td>−0.9 ± 0.7</td>
<td>−1.1 ± 0.7</td>
</tr>
</tbody>
</table>

⁸Based on IPCC 2001 corrected for ocean warming (Keeling & Garcia, 2002; Plattner et al., 2002; Bopp et al., 2002)

Ocean uptake confirmed by ocean inverse (Gloor Gruber, & Sarmiento, 2003), new analysis of oceanic CFC observations (McNeil et al., 2003), & ocean models (Matsumoto et al., in press); Ho & Bender et al. (in preparation)
GFDL has developed a new greatly improved climate model.

Gnanadesikan presentation
Nutrient supply from the Southern Ocean (blue) accounts for 75% of biological productivity outside the Southern Ocean, can affect atmospheric $CO_2$, and is sensitive to climate change.

Sarmiento et al., Nature, 2004; Sigman presentation
The Southern Ocean dominates global biological productivity and CO$_2$, and is sensitive to climate.

Fraction of export production supported by Southern Ocean nutrients

Sigman Presentation
Carbon science

*Carbon science projects* explore the consequences of large-scale carbon management:

- Earth system modeling of the impact of alternative mitigation options on greenhouse gases and climate.

- Analysis of abrupt changes in the carbon and climate system.

- Shipboard measurements of the $O_2/N_2$ ratio of air to estimate natural $CO_2$ sequestration by the land biosphere and oceans.
THE SCIENCE GROUP

**Bender Group - Observational constraints on carbon sinks**
- Improved observationally based carbon sink estimates
- Deployment of oxygen and argon samplers

**Sigman Group - CO$_2$ and Glacial Cycles**
- Stratification of polar oceans during last ice age and influence on atmospheric CO$_2$
- Changes in polar ocean biological productivity, possibly influencing CO$_2$ uptake

**Sarmiento Group + GFDL - The future of the ocean carbon sink**
- Development of new ocean models for carbon and climate simulations
- Climate change impacts on ocean chemistry and biology
- Deep sea injection
- Ocean fertilization

**Pacala Group + GFDL - The future of the terrestrial carbon sink & Impacts of renewable energy**
- Development of new land models for carbon and climate simulations
- Land use vs. fertilization
- Impacts of wind turbines
- Ozone precursors
Science Highlights 2003

1. New observational and model-based estimates of terrestrial and ocean carbon sink size and variability confirm previous estimates.

2. Analysis of Wisconsin forests since the 1960’s indicate growth rates have decreased with rising CO2 levels, undermining the theory that carbon dioxide’s fertilizing effect on land plants would increase CO2 uptake in the future.

3. A new state-of-the-art climate model with an interactive land model has been completed and is running initial simulations.

4. New data indicate that polar oceans were stratified during the last glacial period, supporting the hypothesis that that decreased evasion of CO2 from the deep ocean had a cooling influence on climate.

5. Data from polar oceans provide the first evidence that natural iron variations produce changes in marine biological productivity, possibly influencing CO2 uptake.
Carbon Science

Personnel
Bender  Arbic, Cane, Clark
Morel  Denkenberger, Deutsch
Pacala  Haenssen, Jacobson
Sarmiento  Malyshev, Marinov
Sigman  McKinley, Mignone
Naik, Purves, Reuer
Roy, Shevliakova
Schultz, Simeon
Sturtevant, Weaver
Zea

Core Research
Calculate Stabilization Emissions
Predict Future of Natural Sink
Measure Natural Sinks, Including
via O$_2$/N$_2$ and Ar/N$_2$ Measurements
Predict Climate Change Impacts
Improve Carbon and Climate Models

Tools
Earth System Model
Automated Trace Gas Samplers

Scouts
Iron Fertilization  Glacial/Interglacial
Deep injection  Ecological Sequestration
Climate Change and Wind Energy
Southern Ocean Control of the Global Nutricline (except North Pacific)

Nutrients upwell in the Southern Ocean, flow northward while losing Si(OH)$_4$, and sink into the thermocline as SAMW.

Low Si* water is transported upwards, e.g., in Equatorial upwelling

New Paradigm for the Biological Pump
CFC-11 Inventory
(10^8 Moles)

Anthropogenic CO2 Inventory
(Pg-C)

Outside Southern Ocean

Southern Ocean

Circumpolar Deep Water $\Delta^{14}$C (permil)
AM2p12b

Zonal mean zonal wind, DJF

exp85
mean: 6.6654
std dev: 9.8421

Reanalysis
mean: 6.417
std dev: 9.4734

exp85 - Reanalysis
mean: 0.2486
rms: 1.6558
corr: 0.9967
North Am. Precipitation vs X-A — RMS Errors

Model Number N (AM2pN)

MCM

CM2P10