Role of the ocean on regulating atmospheric $\text{CO}_2$ levels:
1) Ocean natural and anthropogenic $\text{CO}_2$ inventory
2) Magnitude and variability of air-sea $\text{CO}_2$ flux
3) Feedback mechanisms and climate sensitivities for ocean carbon storage
4) Scientific basis for mitigation strategies
Science Background

Historical uptake a function of large-scale circulation; (Present) and future uptake depend on:
- altered physics (warming, stratification, slowed THC)
- response of natural carbon cycle to changes in physics, lower pH, dust, management (direct injection, fertilization)

Biological response & management focus on:
- surface nutrient utilization (Southern Ocean & Fe)
- decoupling of C/N/P (N-fixation, remineralization)
- organic C/CaCO$_3$/SiO$_3$ rain ratios
- community structure

Present models do not include key mechanisms
Implementation Strategy

Research elements
Enabling Activities
Ocean Carbon Observing System
Process Studies
Southern Ocean Pilot Studies
Synthesis and Modeling
Technology Development

Phased basin-by-basin approach:
Existing/ongoing elements (2003-2005)
Phase 1: N. Atlantic and N. and Eq. Pacific (2005-2011)
Phase 2: Southern Ocean (2011- )
Ocean Carbon Observing System

CLIVAR/CO$_2$ Repeat Hydrographic Survey
Decadal-scale time-evolution of natural and anthropogenic CO$_2$ (basin +/- 20%) and related tracers in ocean interior

VOS pCO$_2$ Survey
Improved constraints on air-sea CO$_2$ flux magnitude and seasonal, interannual, decadal variability (+/-0.2 PgC/yr/region)
Open Ocean Time-series & Process Studies
-Ongoing time-series (HOT, BATS, MBARI, ...)  
-New time-series in subpolar, equatorial, coastal biomes  
-Mid-sized process studies linked to existing time-series study (cross-basin and cross-biome)

Continental Margin
Backbone ~12 moored TS Ship transects  
Remote sensing synthesis and in situ calibration  
Process studies in context of existing/new time-series
Remote Sensing
- Ocean color and new bio-optical product development/validation
- Satellite air-sea CO₂ flux products
- Multi-sensor/multi-platform data analysis
OCCC & Remote Sensing

Observing System Elements
- Support of time-series, process studies & North American coastal observing network
- Algorithm development, validation and analysis of ocean color and related remotely sensed bio-optical properties
- Expand in-situ network of sensor calibration sites
- Community-wide technical enabling activities
- Remote-sensing techniques for quantifying air-sea CO₂ flux

Methods/Technology Development
- Operational satellites
- Advanced airborne/space systems
- New/improved algorithms for atmospheric correction, wider suite of bio-optical properties, and coastal waters
- Measurement protocols and in-situ instruments

Synthesis and Modeling
Open Ocean & Coastal Process Studies

- Climate sensitivity of upper water & mesopelagic carbon cycle
  - response to warming, increased surface stratification & lower pH and $CO_3^{2-}$ concentration
  - elemental stoichiometry, temporal variability, export & subsurface remineralization

- Continental margin biogeochemistry
  - land/ocean, sediment/water & shelf/open-ocean exchange
  - biogeochemical transformations/processes (e.g., denitrification, sediment trace metal sources, etc.)

- Air-sea gas exchange
  - direct gas flux measurements (e.g., eddy correlation)
  - physio-chemical controls on gas fluxes
Implementation Strategies for Process Studies

- Mid-sized process studies linked to existing time-series
- Physical oceanographic setting for time-series
- Modeling/data assimilation
- Integrated Northern Hemisphere process study (cross-basin and cross-biome)
- Technology development
  - chemical/biological methods and standards
  - autonomous platforms/sensors
  - genomic techniques
  - remote sensing
North American Carbon Project
measuring and understanding the sources and sinks of \( \text{CO}_2, \text{CH}_4, \) and \( \text{CO} \) in North America and adjacent ocean regions and how are they changing over time

1. Diagnostic Analysis:
   - remote sensing imagery;
   - atmospheric observing system;
   - hydrologic transfers (land=> coastal ocean);
   - open and coastal ocean measurements;
   - modeling (process-based => data assimilation);
   - intensive field campaigns

2. Process-Oriented Research:

3. Predictive modeling:

4. Decision support resources:
The approach we have taken is to coordinate both NACP and OCCC to give us a continuum from dry land to the open ocean.

- NACP will have primary responsibility for land-ocean exchanges.
- Both programs will have responsibility for shelf processes.
- OCCC will have primary responsibility for shelf-open ocean exchanges.
Timeline of OCCC Implementation Strategy

2003

Existing Time-series Stations (e.g., HOT, BATS, CARIACO, Monterey Bay...)

Repeat Hydrographic, & VOS pCO₂ Surveys, Remote Sensing

2004

Steering Committee, OCCC Project and Data Management Offices

Enabling Activities (Workshops, Education & Outreach, National & International Linkages)

Technology Development (Sensors, Platforms, Techniques, Remote Sensing)

Synthesis and Modeling, Experimental Design, Southern Ocean Synthesis

2005

Mid-size Process Studies at Existing Time-series Stations

New Time-series in Subpolar, Equatorial, Continental Margins

North American Coastal Observing System

Southern Ocean Pilot Field Studies

Large-scale Northern Hemisphere Process Study

Establish Southern Ocean Time-series

2006

2007

2008

2009

2010

2011

2012

2013

Southern Ocean Process Study
OCCC Status and Issues

- Technology development, synthesis & modeling, and enabling activities (2005=>)
- Mid-size process studies at an existing time-series and coastal site (2006 =>)
- Large Northern Hemisphere process study (2008=>)
New Oversight Structure

- OCCC Scientific Steering Group
  - ~8 individuals w/ balanced NASA, NSF and NOAA perspective
- Ocean Carbon & Biogeochemistry SSC
  - ~20 individuals w/ more NSF emphasis
  - Includes OCCC SSG members
  - Broader purview of OCCC, U.S. SOLAS, U.S. IMBER
U.S. Interagency Carbon Cycle Science Program (4/1/05): Organization to Accommodate Ocean BGC SSC & Project Office

Carbon Cycle Interagency Working Group (CCIWG)

NACP SSG

NACP Office

OCCC SSG

OCCC Office

NACP PIs

OCCC PIs

Plug-in to Ocean BGC SSC and Project Office

Carbon Cycle Science Steering Group (CCSSG)
U.S. Interagency Carbon Cycle Science Program (4/1/05):
Ocean Biogeochemistry SSC and Project Office

U.S. Ocean Carbon & Biogeochemistry Steering Committee

Plug-in to CCSP OCCC SSG and Office

U.S. Ocean Carbon & Biogeochemistry Project & Data Management Offices

OCCC-/ IMBER-/SOLAS-/Other-Indentified Investigators
**OCCC Status & Issues (cont.)**

**Field Project & Data Management Offices**
- NSF supported informal AO Summer 2005
- "Stop-gap" coordination and data management project
  - host OCCC summer workshop 2005
  - collect/serve data from existing mid-sized projects (Eddies, SOFEX, Vertigo, MedFlux ...)

**Science & Coordination Meetings**
- OCCC Ocean Carbon Science Meeting
  - Woods Hole, MA August 1st-4th 2005
- Joint OCCC/NACP Coastal Ocean Carbon Workshop
  - Sept. 2005 in Boulder CO (week before International Carbon Conference)
OCCC Status & Issues (cont.)

OCCC Research Implementation

- Identify and assemble OCCC Science Team
  - draw members from existing and new OCCC labeled programs
  - CLIVAR/CO₂ survey, VOS lines, time-series, NSF ICCR projects and mid-sized projects, NASA Ocean color team, etc.
  - plan Science team meeting for spring/summer 2006

- Task SSG, Science Team & Field Project Office with fleshing out detailed implementation plans
  - technology development;
  - synthesis and modeling;
  - mid-sized process studies;
  - new time-series;

- Coordinate with U.S. and international partners
  - U.S. and international SOLAS, IMBER
  - U.S. CLIVAR process studies and ORION
  - Carbo-Ocean
OCCC Status & Issues (cont.)

OCCC Management Structure
- Wide range of project sizes from individual PIs to mid-size and “large” coordinated field studies
- Federated or decentralized structure that allows for greater flexibility as the science evolves
- Data management & science meetings as unifying elements
Funding Opportunities
- NSF-Geo Biocomplexity (Water and Carbon)
- NSF ORION (Coastal site definition)
- NASA ROSES (Biological Oceanography; NACP)
- NOAA-OGP (no carbon funding round this year)
- DOE
- Other?