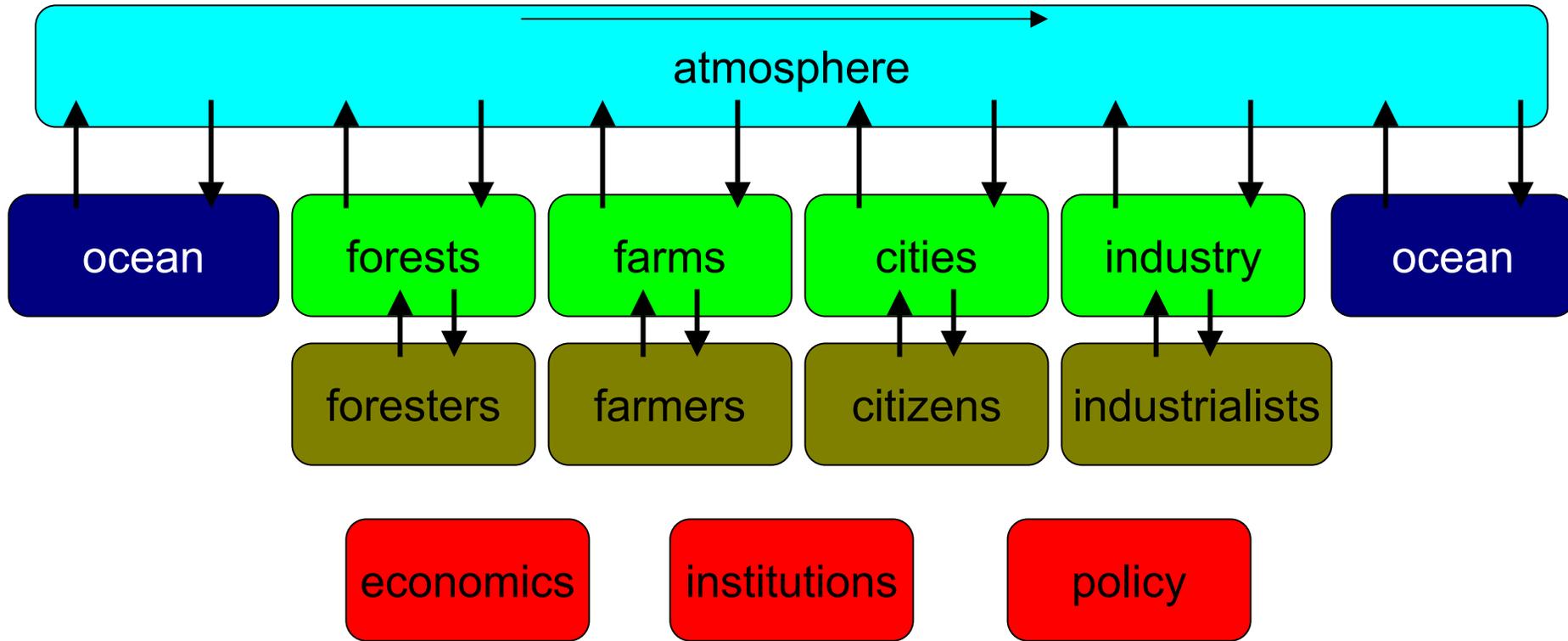


North American Carbon Program

Scott Denning, Chair
NACP Science Steering Group



Sources, Sinks, and Processes

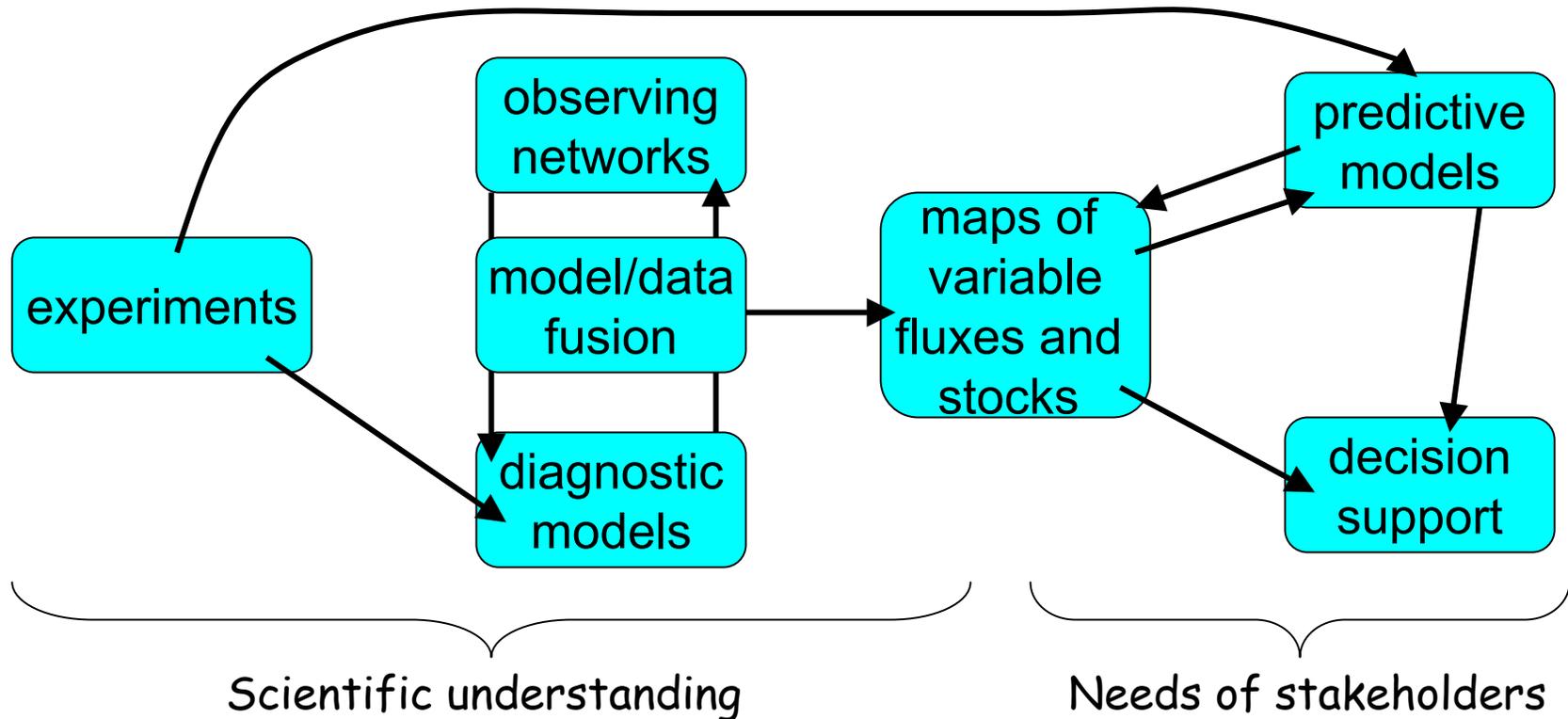


- Carbon exchanges with the atmosphere over North America are managed by people
- Understanding and predicting these exchanges will require quantification of management effects

NACP Questions

1. What is the carbon balance of North America and adjacent oceans? What are the geographic patterns of fluxes of CO_2 , CH_4 , and CO ? How is the balance changing over time? ("*Diagnosis*")
2. What processes control the sources and sinks of CO_2 , CH_4 , and CO , and how do the controls change with time? ("*Attribution/Processes*")
3. Are there potential surprises (could sources increase or sinks disappear)? ("*Prediction*")
4. How can we enhance and manage long-lived carbon sinks ("sequestration"), and provide resources to support decision makers? ("*Decision support*")

NACP Integration Strategy



- **Process studies** and manipulative **experiments** inform **improved models**
- **Systematic observations** used to evaluate models
- Innovative **model-data fusion** techniques produce optimal estimates of **time mean** and **spatial and temporal variations in fluxes and stocks**
- Improved models **predict future variations**, **tested** against ongoing diagnostic analyses
- Predictive models and continuing analyses used to **enhance decision support**

Research Elements: Question 1

Diagnosis of Current Carbon Budgets

- A hierarchical approach for large-scale, **distributed terrestrial measurements**
- Substantially improved **fossil fuel emissions inventories** with high resolution **downscaling** in time and space, and methods for evaluating these inventories using atmospheric measurements
- **Hydrologic transfers of carbon** over land, and sequestration in sediments
- **Ocean measurements and modeling**, both in the coastal zone and the open ocean, in coordination with the *OCCC*
- An **atmospheric observing system** consisting of ground stations, aircraft and measurements from towers
- **Spatially-distributed modeling** of carbon cycle processes
- **Model-data fusion** and data assimilation to produce optimal estimates of spatial and temporal variations that are consistent with observations and process understanding
- Interdisciplinary **intensive field campaigns** designed to evaluate major components of the model-data fusion framework

Hierarchical Terrestrial Measurements for integration

“Wall-to-wall” remote sensing and other spatial data 10^7

Extensive inventories (Forest and Cropland) 10^5

- More than 170,000 sites at 5-10 yr intervals
- Complementary networks in Canada & Mexico

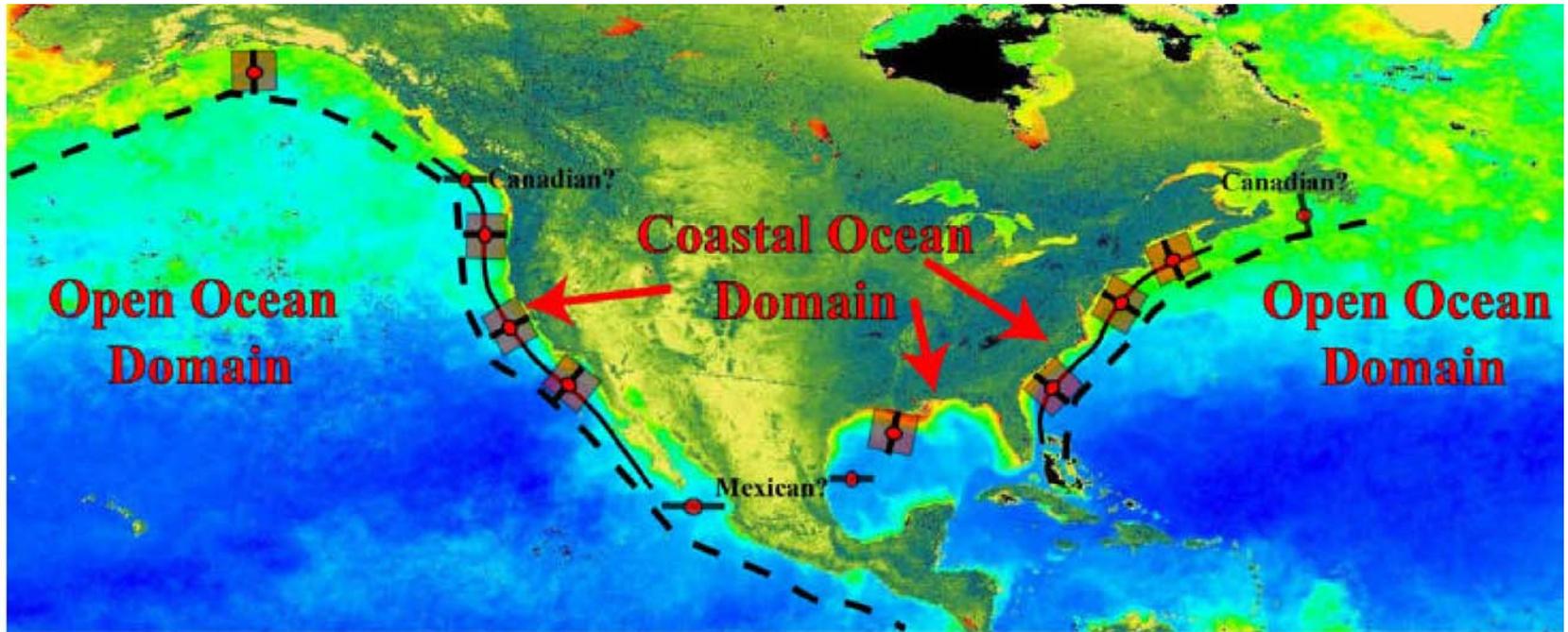
Intermediate intensity sampling at many sites , to facilitate scaling from local fluxes to regional modeling with RS/GIS (new) 10^3

Very intensive investigation of processes (10^2)

- ~ 100 flux towers, long-term ecological research sites, etc
(Links to NEON?)

NACP Question 1: Diagnosis of current carbon budgets

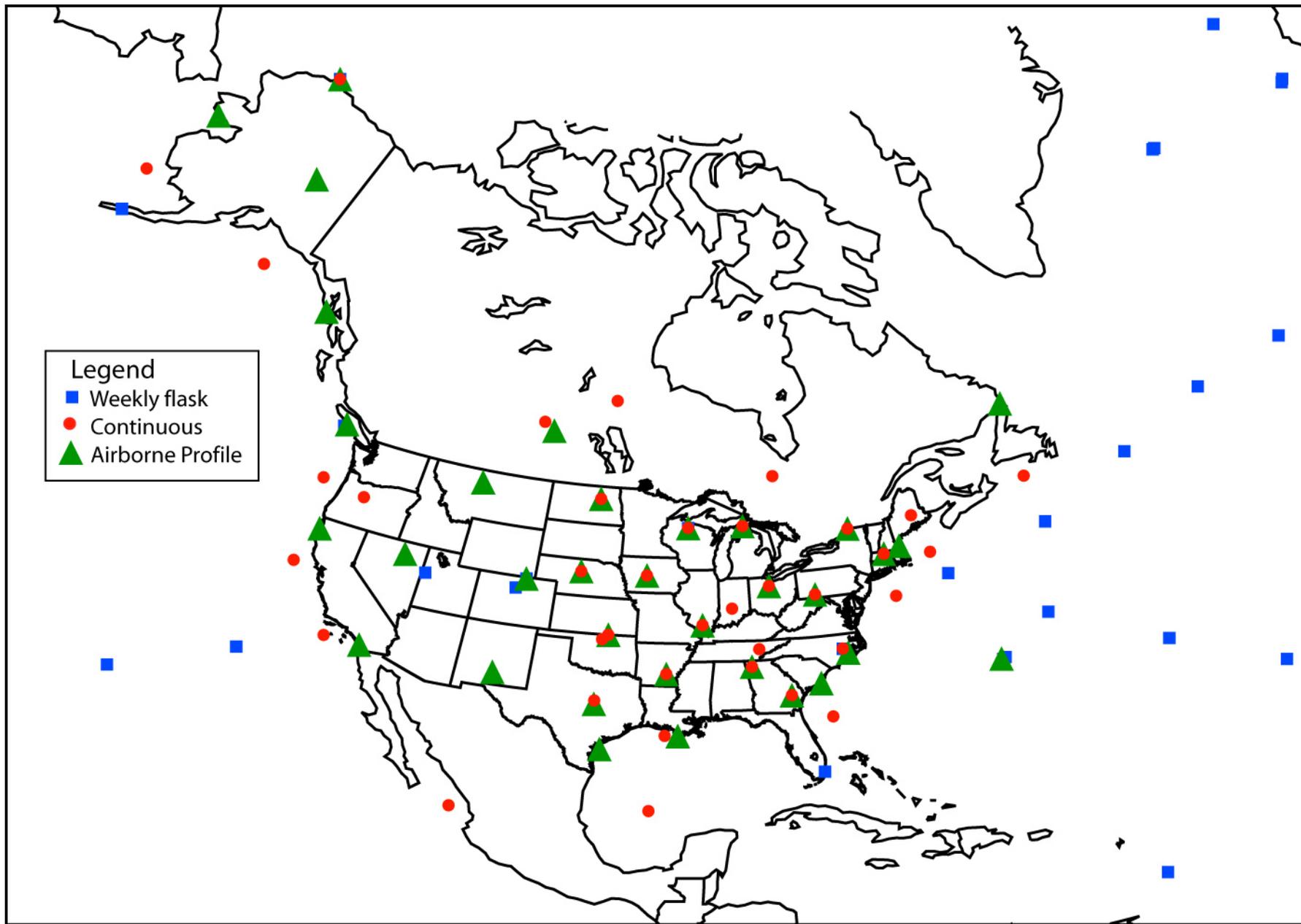
Ocean Observations and Modeling



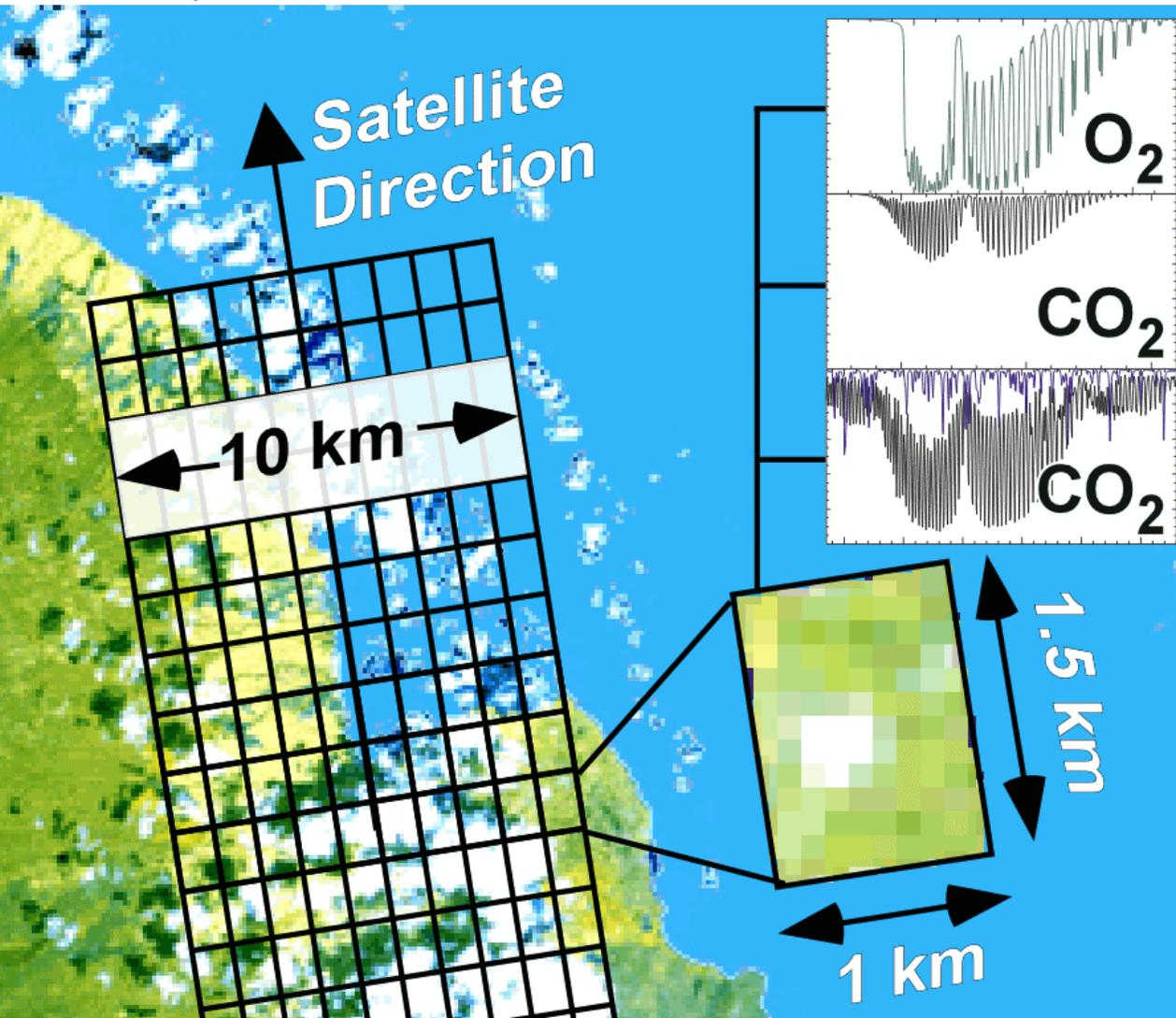
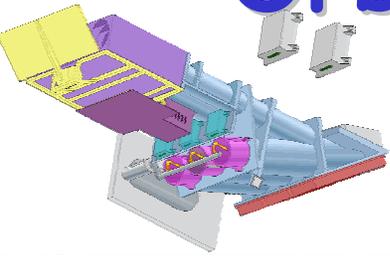
- Coastal carbon burial and export to the open ocean
- River-dominated margins and coastal upwelling regions merit special attention due to their dominant role in coastal carbon budgets
- Coordination with US Ocean Carbon & Climate Change program

NACP Question 1: Diagnosis of current carbon budgets

NACP Atmospheric [CO₂] Network



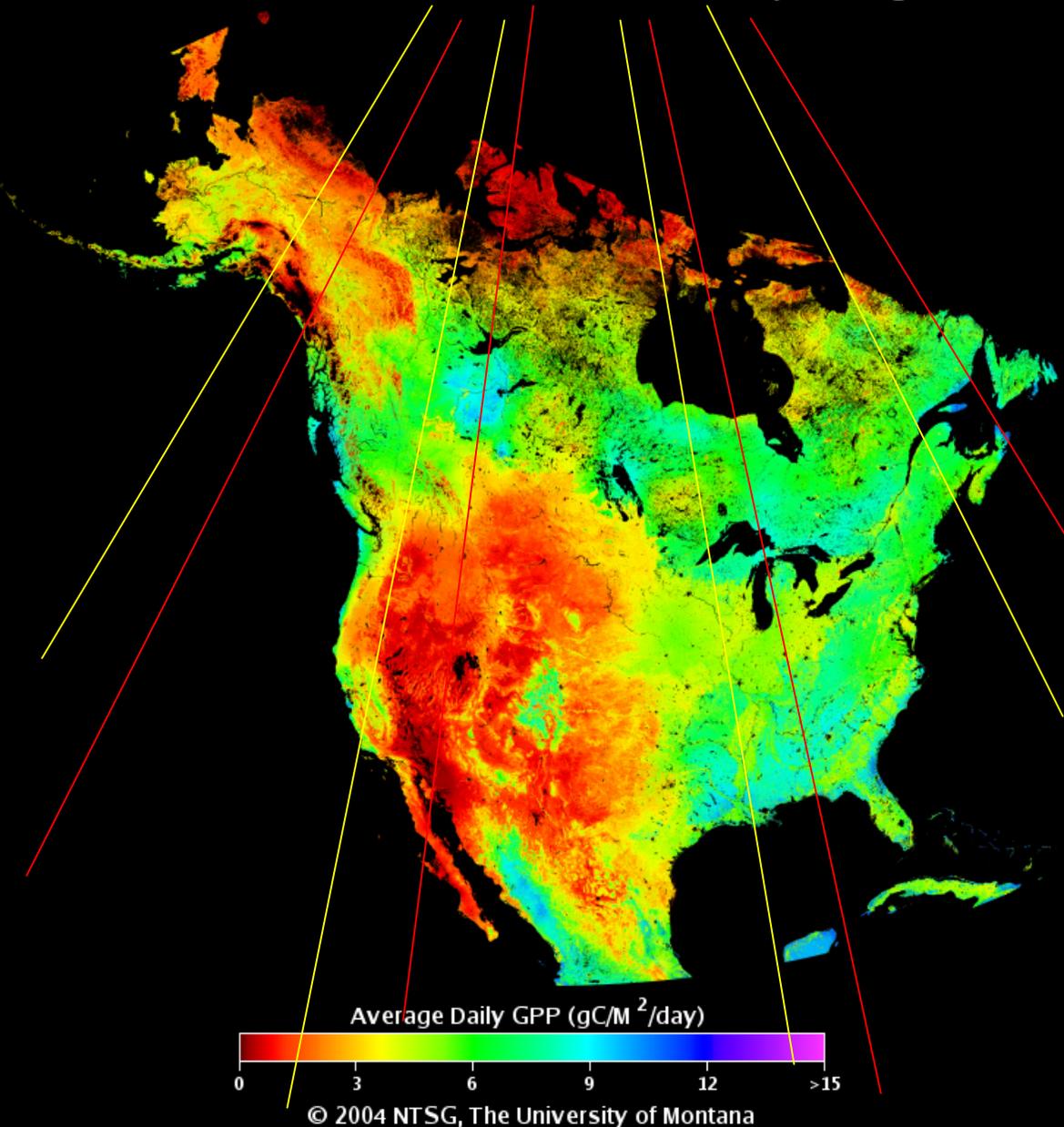
Orbiting Carbon Observatory (Planned 2008 launch)



- Estimated accuracy for single column ~1.6 ppmv
- 1 x 1.5 km IFOV
- 10 pixel wide swath
- 105 minute polar orbit
- 26° spacing in longitude between swaths
- 16-day return time

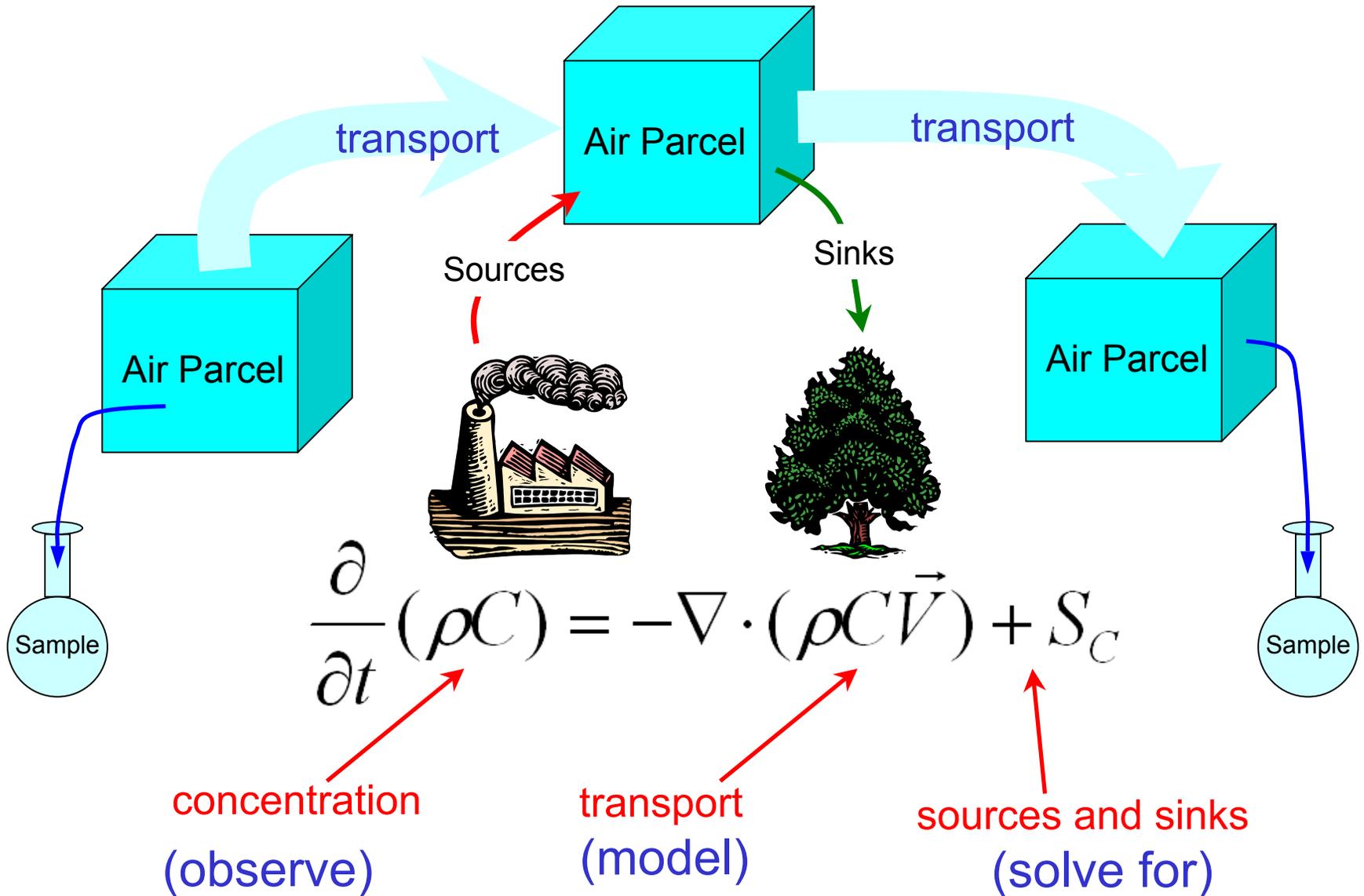
1 Day of North American OCO Data

MOD17A2 v105 (Enhanced GPP) over North America, July 28 - August 4, 2003



- Three very narrow (10 km) swaths over N. America per day
- Most of domain will be **outside of strongest influence of observations**
- Spatial autocorrelation length scale?
- Are **tomorrow's fluxes the same?**
- Need to handle temporal covariance

Inverse Modeling



Top-down Integration using atmospheric inverse models

- Atmospheric synthesis inversion using high-resolution transport and small regions tied to process characterization
- Newer approaches using Lagrangian particle dispersion, adjoint transport, variational methods (e.g., 4DVAR), or Ensemble Kalman Filter (EnKF)
- Combination of periodic large-scale constraint from airborne and flask sampling with continuous data
- Inclusion of satellite data
- Multi-gas inversions for source attribution

NACP Question 1: Diagnosis of current carbon budgets

Spatially Distributed Process Modeling

bottom-up integration

- Models of terrestrial ecosystem **fluxes, calibrated and tested against local data**
- “Slow” ecosystem dynamics: **disturbance, succession, soil carbon biogeochemistry**
(Spatial mapping of carbon stocks)
- Agroecosystem modeling
(**irrigation, fertilization, harvest**, etc)
- Fossil fuel **emissions**
(downscaled in space and time from inventories)
- Coastal upwelling, **air-sea fluxes**, sedimentation

NACP Question 1: Diagnosis of current carbon budgets

Model-Data Fusion (a.k.a. Data Assimilation)

- Analogous to weather forecasting
- Uses best process-based, deterministic models of key carbon fluxes and pools
- Identification of key parameters that control uncertainty in final maps
- Optimization of parameters according to all available observations (space and time)
- Produces analyzed fields of fluxes and stocks that are optimally consistent with disparate observations and process understanding

NACP Question 1: Diagnosis of current carbon budgets

Diagnostic Analyses

optimal process-based estimates at highest appropriate space/time resolution

- Photosynthesis, respiration, decomposition
- Combustion emissions (CO_2 , CO , CH_4) including diurnal and weekly cycles
- Storage of carbon in forests, grasslands, crops, fuel, rivers, reservoirs, estuaries, sediments
- Transfers among pools
- Net fluxes of CO_2 , CO , CH_4 to the atmosphere
- Finely resolved 3D grids of CO_2 , CO , CH_4 in the atmosphere at hourly intervals

NACP Question 1: Diagnosis of current carbon budgets

Research Elements: Question 2

Processes Controlling Carbon Budgets

- Terrestrial carbon response to changes in atmospheric CO_2 , tropospheric ozone, nitrogen deposition, and climate
- Responses of terrestrial ecosystems to changes in disturbance regimes, forest management, and land use
- Responses of terrestrial ecosystems to agricultural and range management
- The impacts of lateral flows of carbon in surface water from land to fresh water and to coastal ocean environments
- Estuarine biogeochemical transformations;
- Coastal marine ecology and sedimentation;
- Air-sea exchange and marine carbon transport; and
- Human institutions and economics: use this research and modeling, or develop new research in this element?

Flux Towers

- Calibration

IRGA - WMO gas stds.

Temperature

Net Radiation

PPFD

- Intercomparisons

Fluxes: H, LE, CO₂

Met: T, Rn, PPFD

30 sites, 8 countries

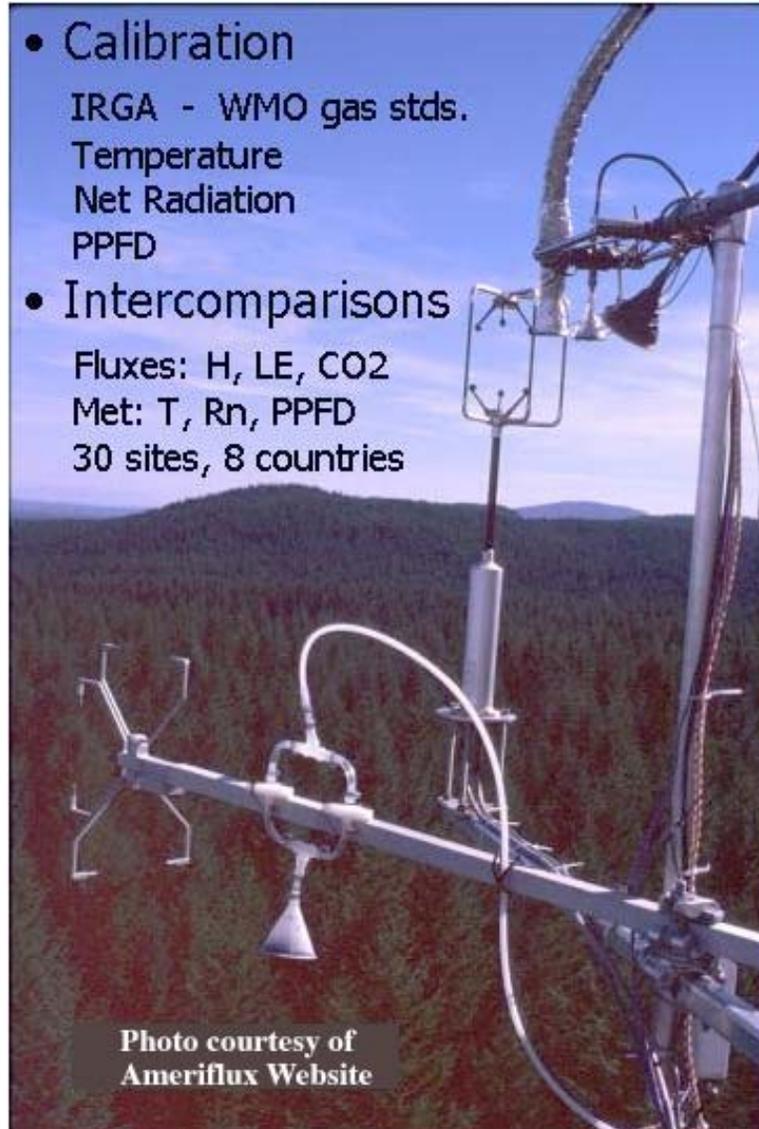
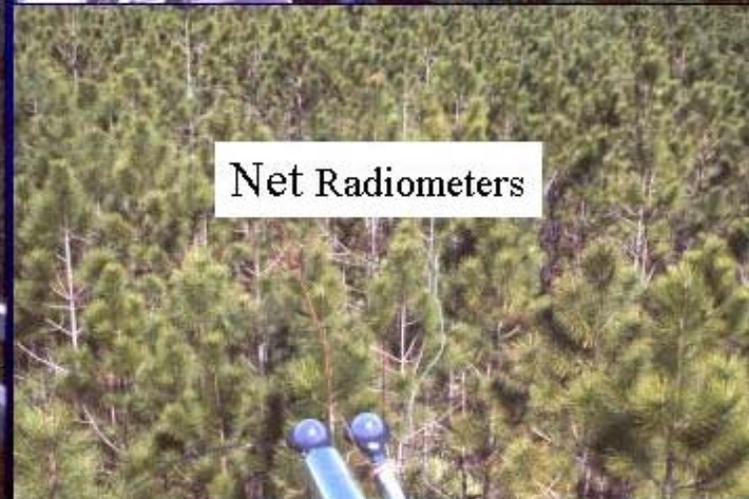


Photo courtesy of
Ameriflux Website



Temp aspirators



Net Radiometers

Free Air Carbon Enrichment (FACE)



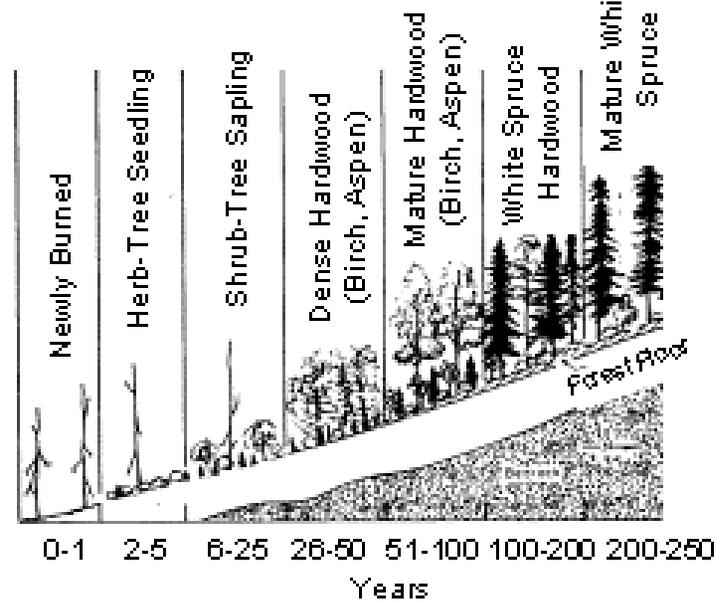
- Fumigation rings maintain steady levels of elevated CO_2 in canopies under changing weather conditions
- Control and replicated treatments test effects of CO_2 , water, N, etc

Disturbance



Recovery!

Upland White Spruce Succession On South Slopes Near Fairbanks, Alaska Following Fire



Forest Inventory Analysis



- Plot-scale measurement of carbon storage, age structure, growth rates
- Allows assessment of decadal trends in forest carbon storage

Program Elements: Question 3

Predictive Modeling

- Transfer of synthesized information from **process studies into prognostic carbon-cycle models**
- **Retrospective analyses** to evaluate the spatial and temporal dynamics of disturbance regimes simulated by prognostic models
- **Evaluation** of predictions of interannual variations with predictive models against continued monitoring using observational networks and diagnostic model-data fusion systems
- Development of **scenarios of future changes** in driving variables of prognostic models
- Application and **comparison of prognostic models** to evaluate the sensitivity of carbon storage into the future
- Incorporation of prognostic models into **coupled models of the climate system**

Program Elements: Question 4

Decision Support

- North American contribution to the **State of the Carbon Cycle Report (SOCCR)**
- Analysis of the **longevity of sinks**
- **Assessment of sequestration options** given best scientific evaluation of present and future behavior of carbon cycling
- Provide scientific understanding to inform **management of the carbon cycle** given improved understanding, diagnosis, and prediction
- Early detection of carbon cycle risks and vulnerabilities
- **Scenario development** for simulation of future climate

NACP Intensive Field Campaigns

- Motivation: evaluate integrated observing/modeling/assimilation system in a "testbed" for which all relevant variables are "oversampled"
- Several IFCs may be required, to test various aspects of coupled analysis system
 - Crops & managed carbon fluxes with atmospheric sampling and inversion
 - Forest management, tiered sampling, biomass inventories
 - Combustion emissions inventory downscaling with detailed downwind trace gas measurements
 - Synoptic and cloud-scale meteorology and trace gas transport
- Goal is a well-tested observing and analysis system with documented uncertainties that we understand

First NACP IFC

- Mid-continent focus: 2005-2006
- Upper Midwestern United States
 - eastern South Dakota, eastern Nebraska, eastern Kansas, northern Missouri, Iowa, southern Minnesota, southern Wisconsin, and Illinois
 - Some elements of experiment may include larger or smaller areas
- Reconcile estimates of sources and sinks derived from atmospheric models using measurements of trace gas concentrations with direct estimates based on field measurements, inventories, regional geographic information, and remote sensing
- Attribution of sources and sinks to ecosystem processes and human activities within the region

NACP Question 1: Diagnosis of current carbon budgets

NACP Workshops

- **Remote Sensing** for NACP
(Missoula, Montana, August 2004)
- **Agricultural data** and modeling in support of an NACP mid-continent **intensive** study
(Des Moines, Iowa, September 2004)
- **In-situ observations** and modeling in support of the mid-continent **intensive**
(Boulder, Colorado, October, 2004)
- NACP Science Symposium (**Fall AGU**, ~80 papers!)
- NACP **Data Management**
(New Orleans, January, 2005)