Synthesis of Arctic System Carbon Cycle Research Through Model-Data Fusion Studies Using Atmospheric Inversion and Process-Based Approaches

(SASS PI Meeting – 26-27 March 2006)

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Institute of Arctic Biology - University of Alaska Fairbanks

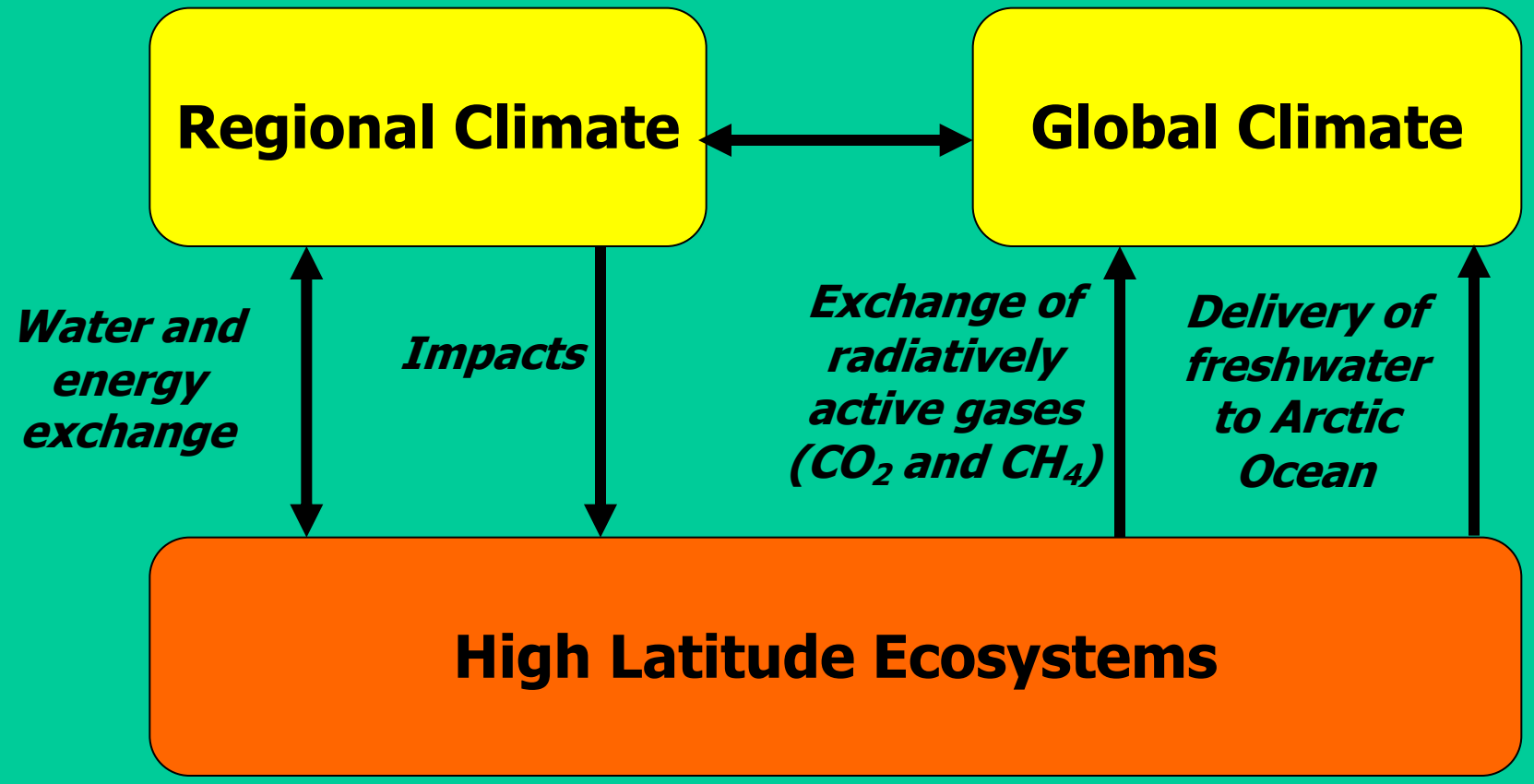
Project Participants

- McGuire - UAF
- Melillo, Kicklighter, Peterson - MBL
- McClelland – Texas A&M
- Follows, Prinn - MIT
- Zhuang - Purdue

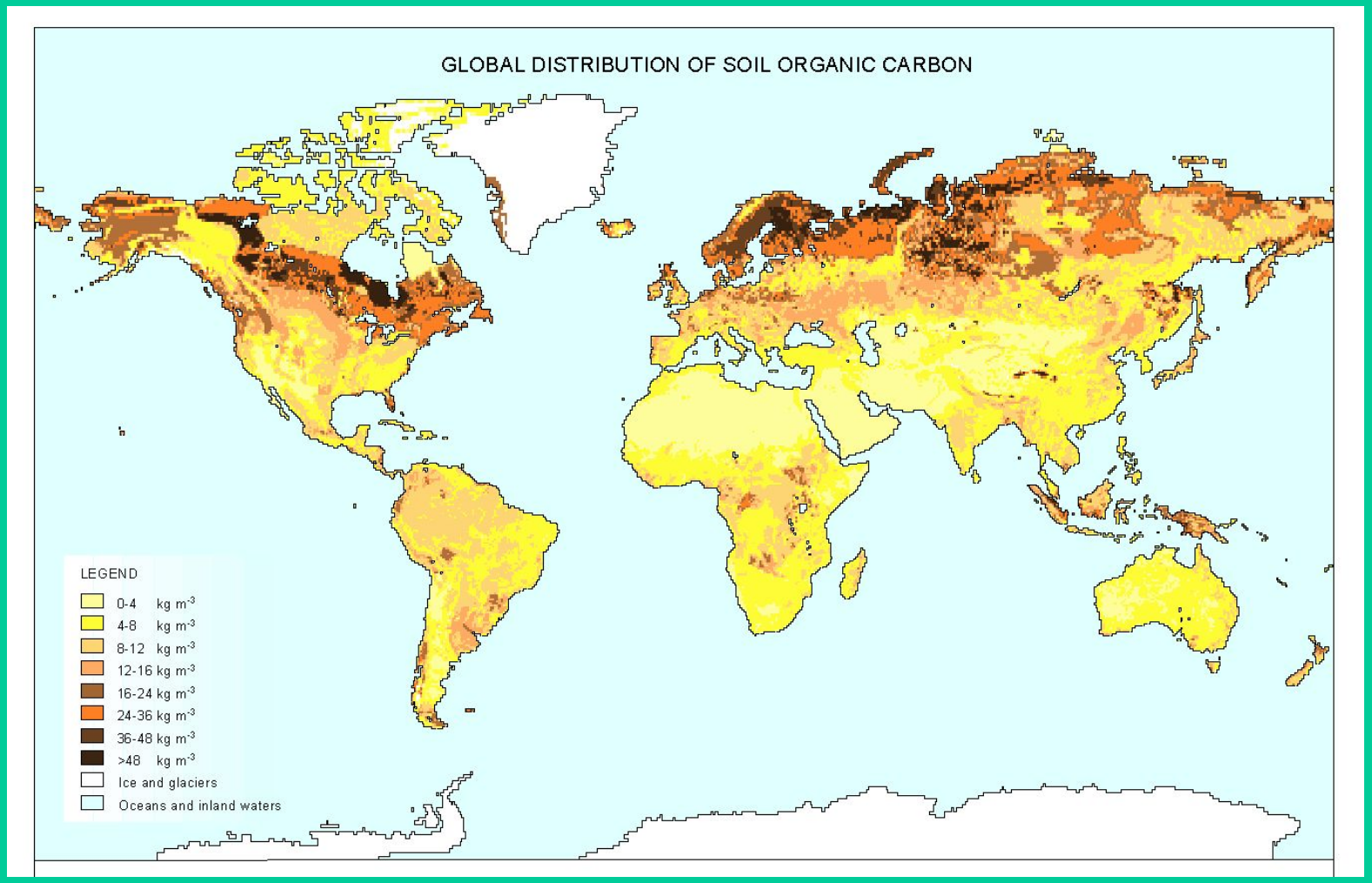
Project Overview

- Background
- General Questions
- General Strategy
- Tasks
- Time Line
- Education and Outreach

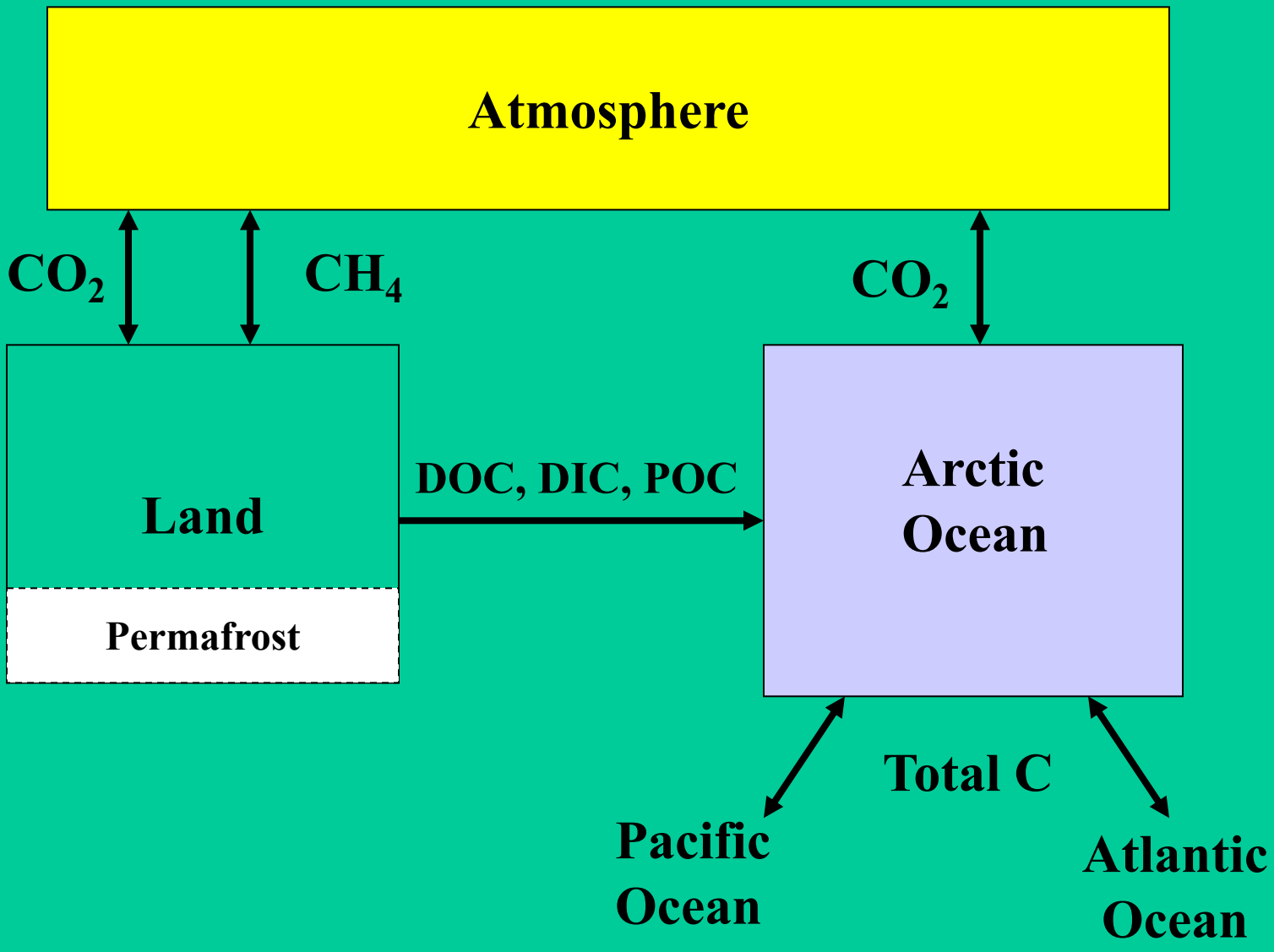
Interactions of High Latitude Ecosystems with the Earth's Climate System



32-44% of global soil carbon stored in high-latitudes



Key Fluxes of Carbon in the Arctic System

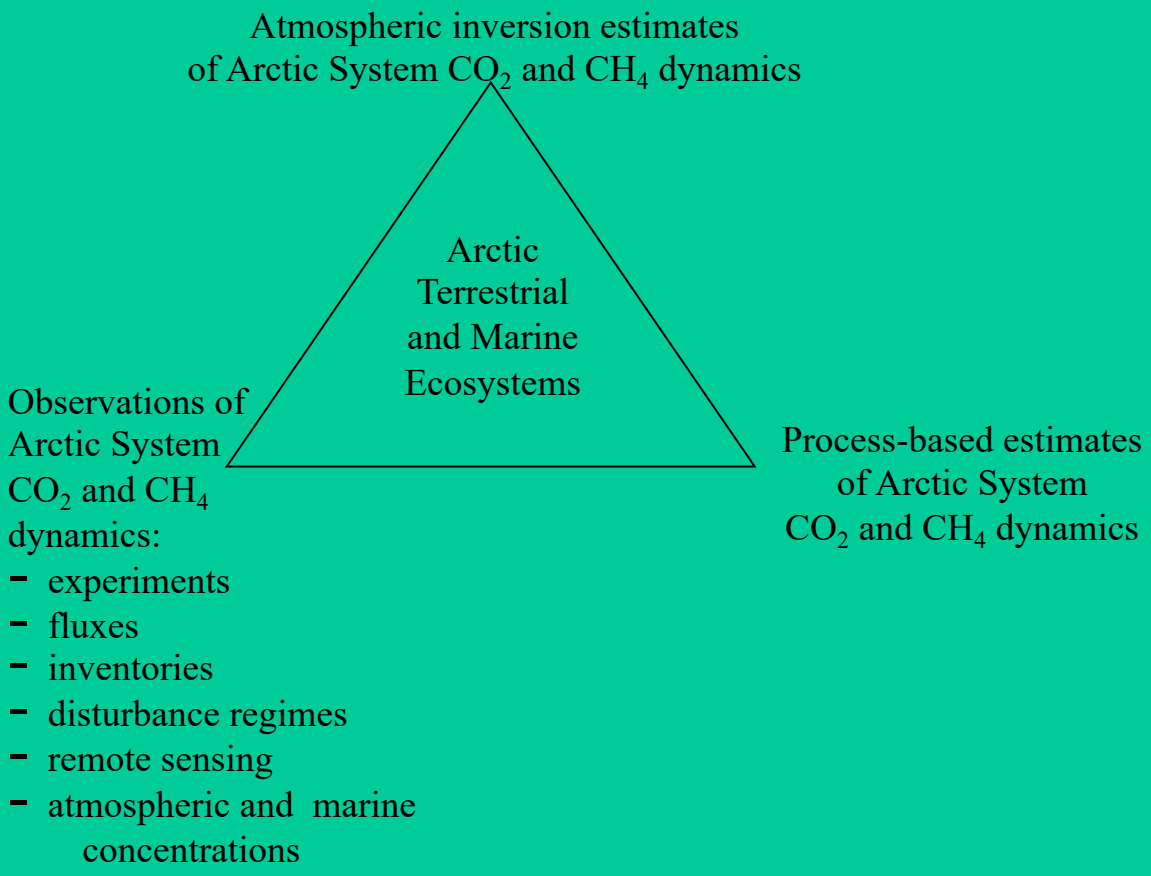


General Questions Guiding Research

1. *What are the geographic patterns of fluxes of CO_2 and CH_4 over the Pan-Arctic region and how is the balance changing over time? (Spatial Patterns and Temporal Variability)*

2. *What processes control the sources and sinks of CO_2 and CH_4 over the Pan-Arctic region and how do the controls change with time? (Processes and Interactions)*

General Strategy: Model-Data Fusion



Tasks

1. Conduct model-data fusion studies with process-based models of various components of high latitude terrestrial C dynamics including
   a. Terrestrial CO_2 (McGuire lead) and CH_4 exchange (Zhuang lead), and
   b. Transfer of C from high latitude terrestrial ecosystems to the mouth of rivers in the Pan-Arctic Drainage Basin (Melillo/Peterson/McClelland/Kicklighter lead)

2. Conduct model-data fusion studies with a process-based model of marine CO_2 exchange in oceans adjacent to the high latitude terrestrial regions (Follows lead)

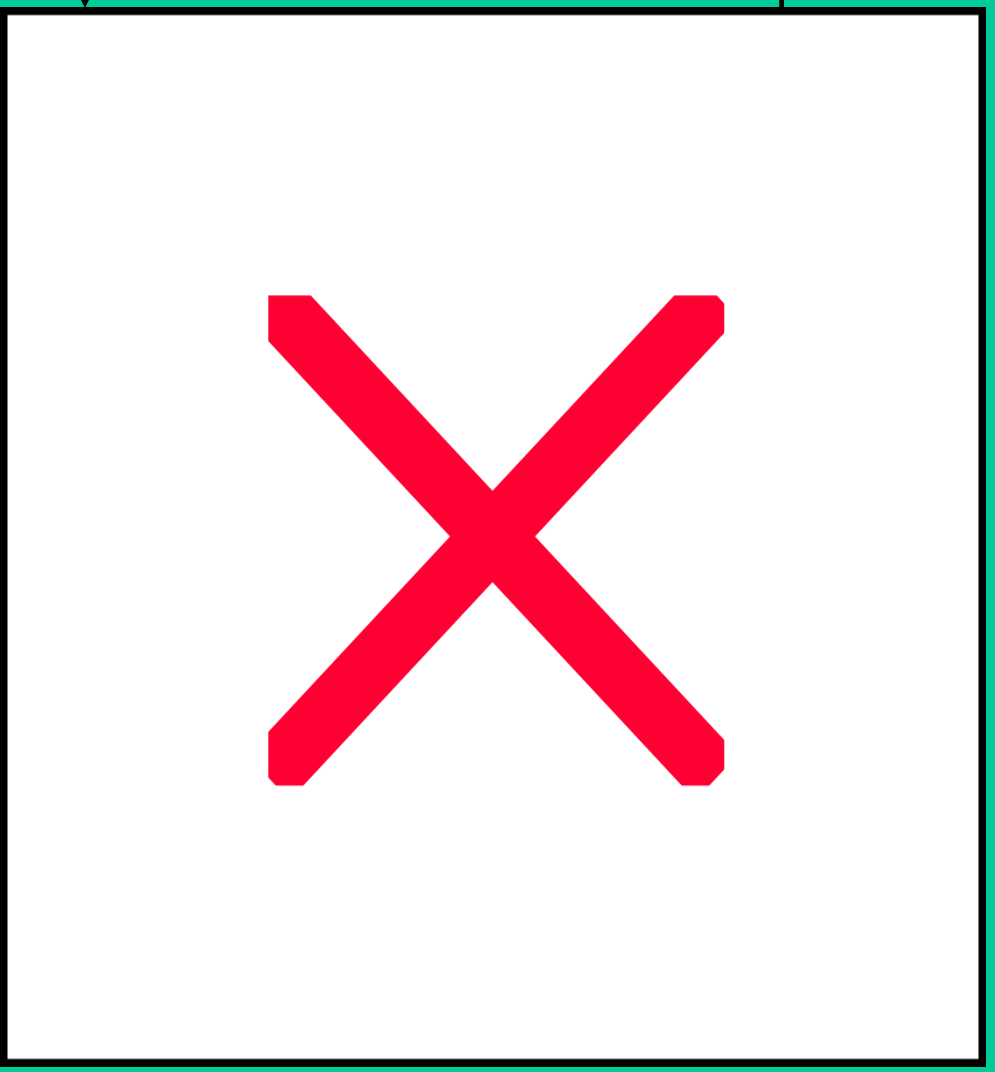
3. Improve atmospheric inversions of CO_2 and CH_4 across high latitude regions through better incorporation of data and process-understanding on CO_2 and CH_4 dynamics (Prinn lead).

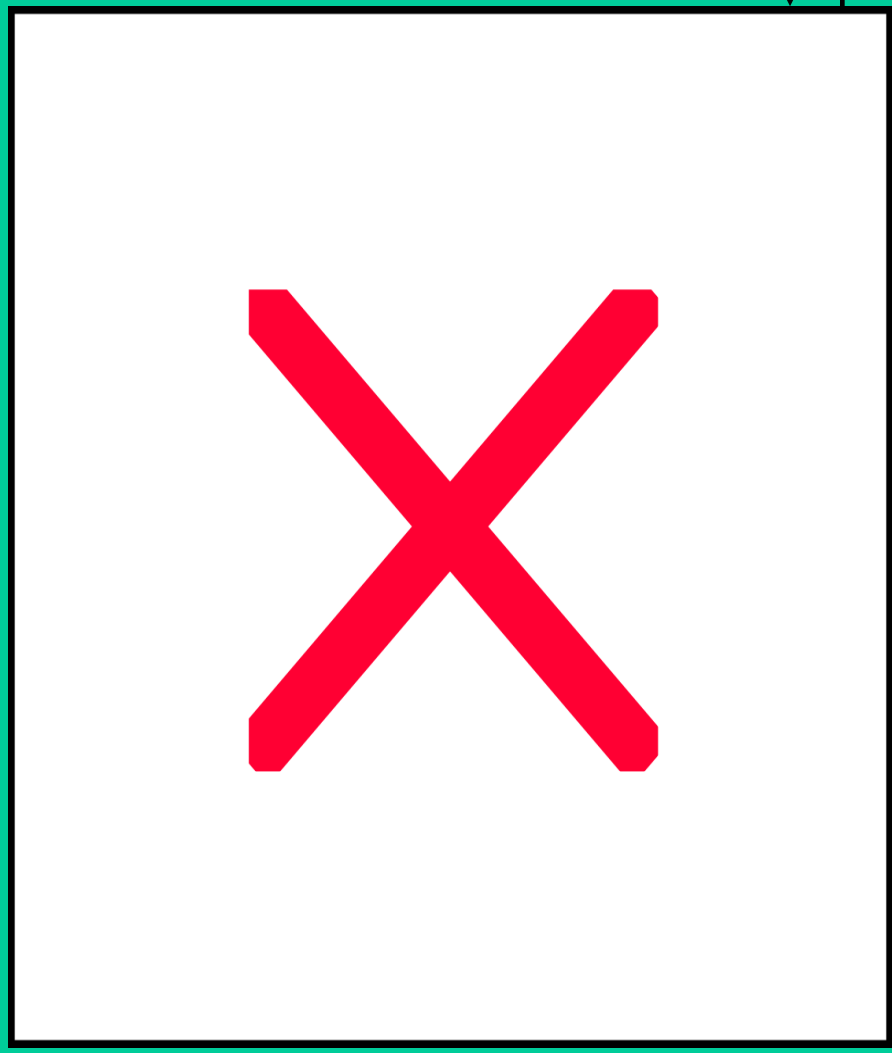
4. Project synthesis (All).

Tool for Process-Based Terrestrial CO_2 Exchange

Soil temperature

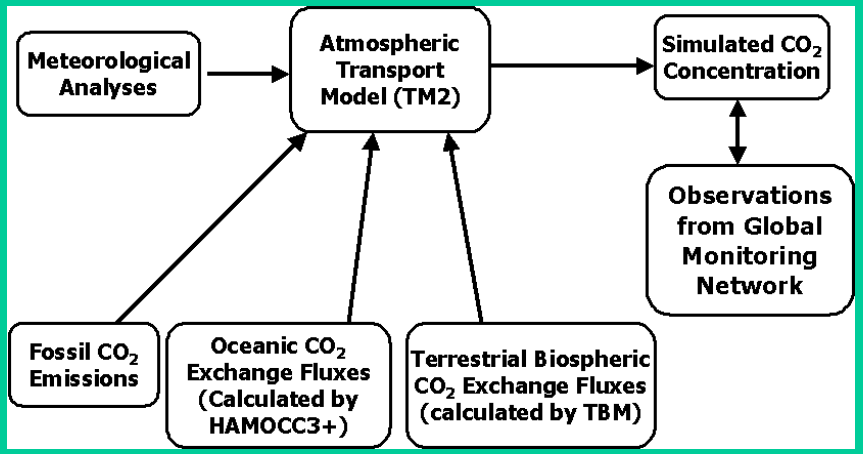
Vegetation type;Snow pack; Soil moisture



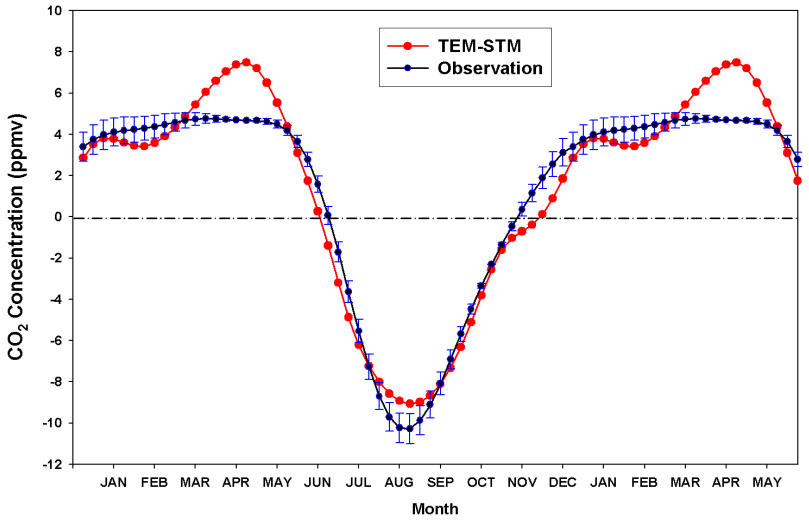


Terrestrial Ecosystem Model (TEM) couples biogeochemistry and soil thermal dynamics

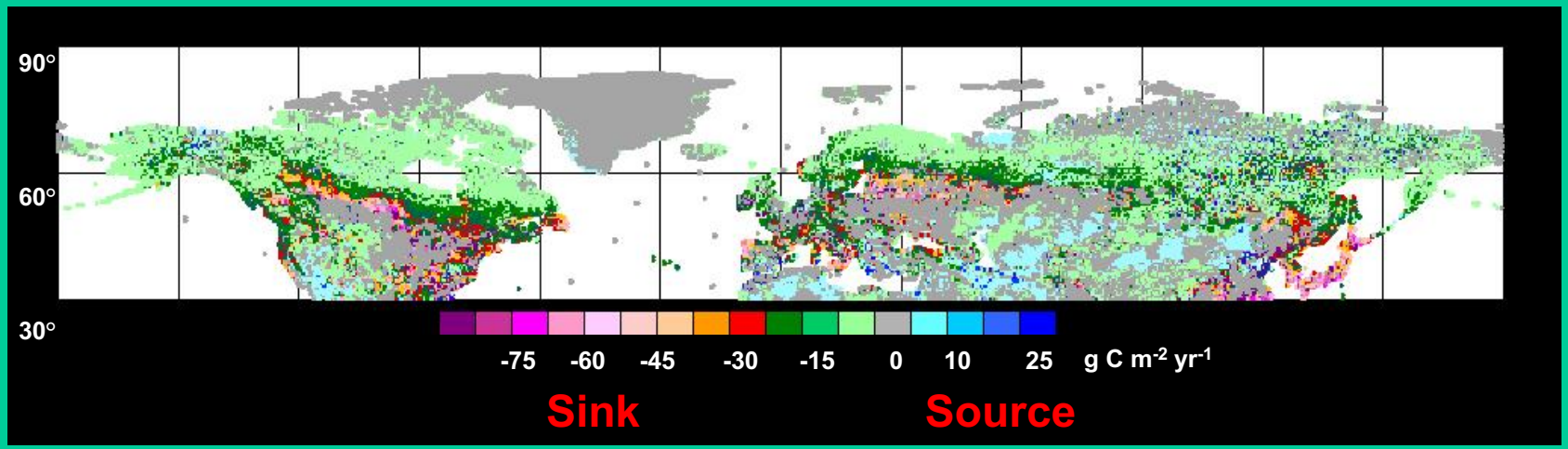
Strategy to evaluate seasonal exchange of carbon dioxide simulated by terrestrial biosphere models



Observed and simulated atmospheric CO_2 concentrations at Mould Bay Station, Canada (-119.35°W, 76.25°N) during the 1980s

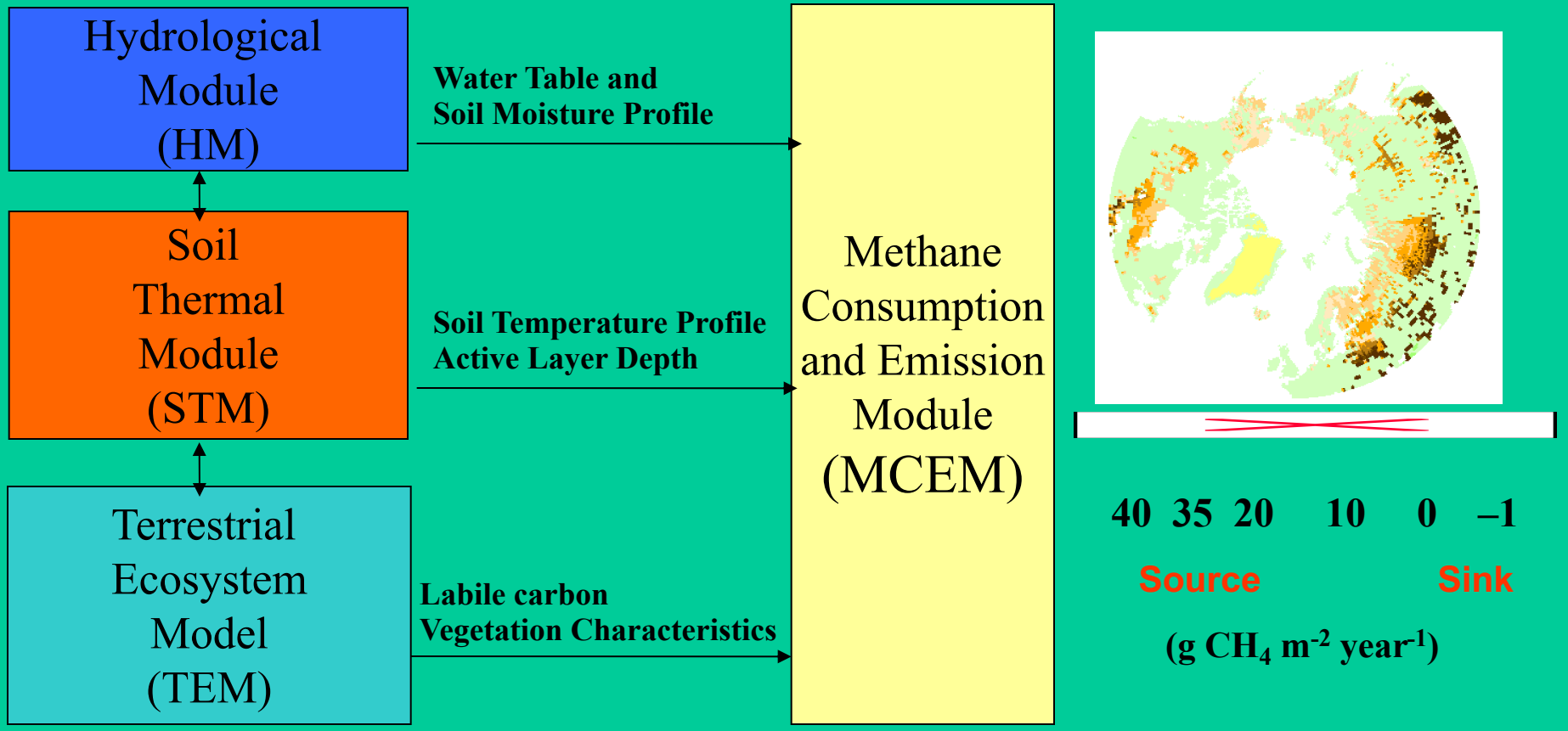


Spatial patterns of change in vegetation carbon over the twenty year period spanning from 1980-2000 as simulated by the Terrestrial Ecosystem Model (TEM)

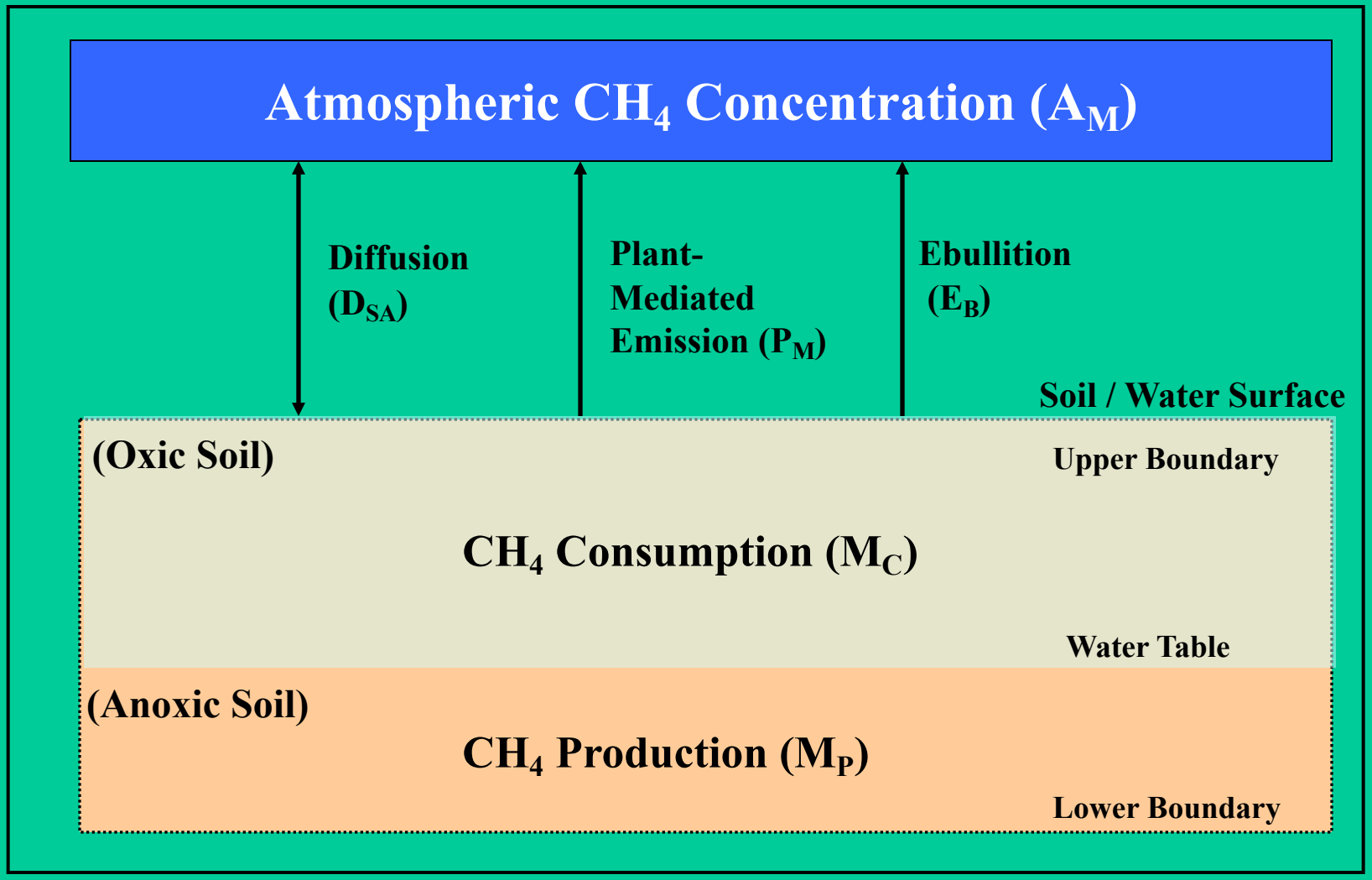


Incorporation of freeze-thaw dynamics into the Terrestrial Ecosystem model improves the simulation of the seasonal and decadal exchange of carbon dioxide exchange with the atmosphere (Zhuang, Euskirchen, McGuire, Melillo, Romanovsky)

Tool for Process-Based Terrestrial CH_4 Exchange



Methane Consumption and Emission Module



(Zhuang et al., 2004 GBC)

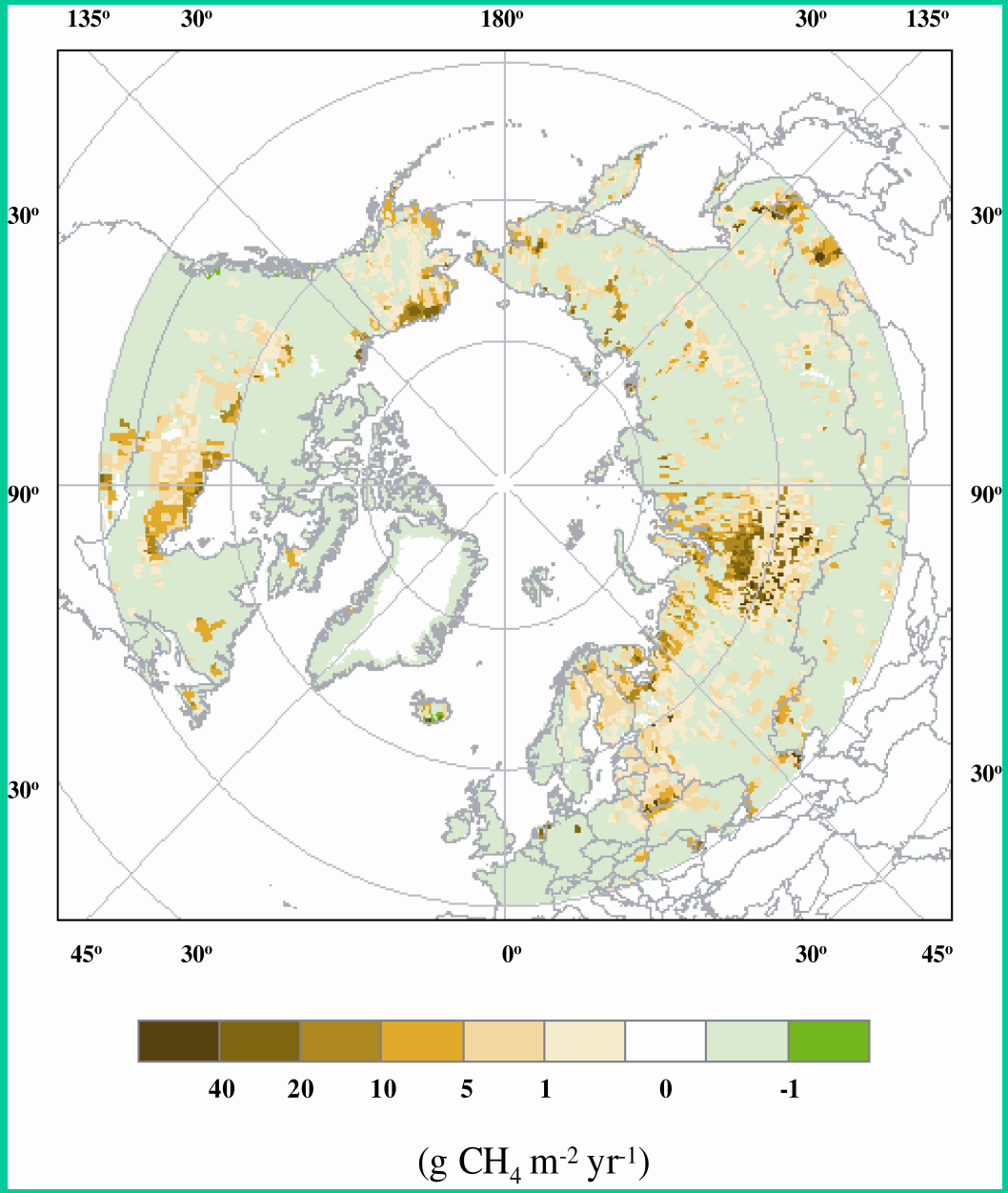
Net Methane Fluxes in the 1990s

Emissions
= 56 Tg CH_4 yr^{-1}

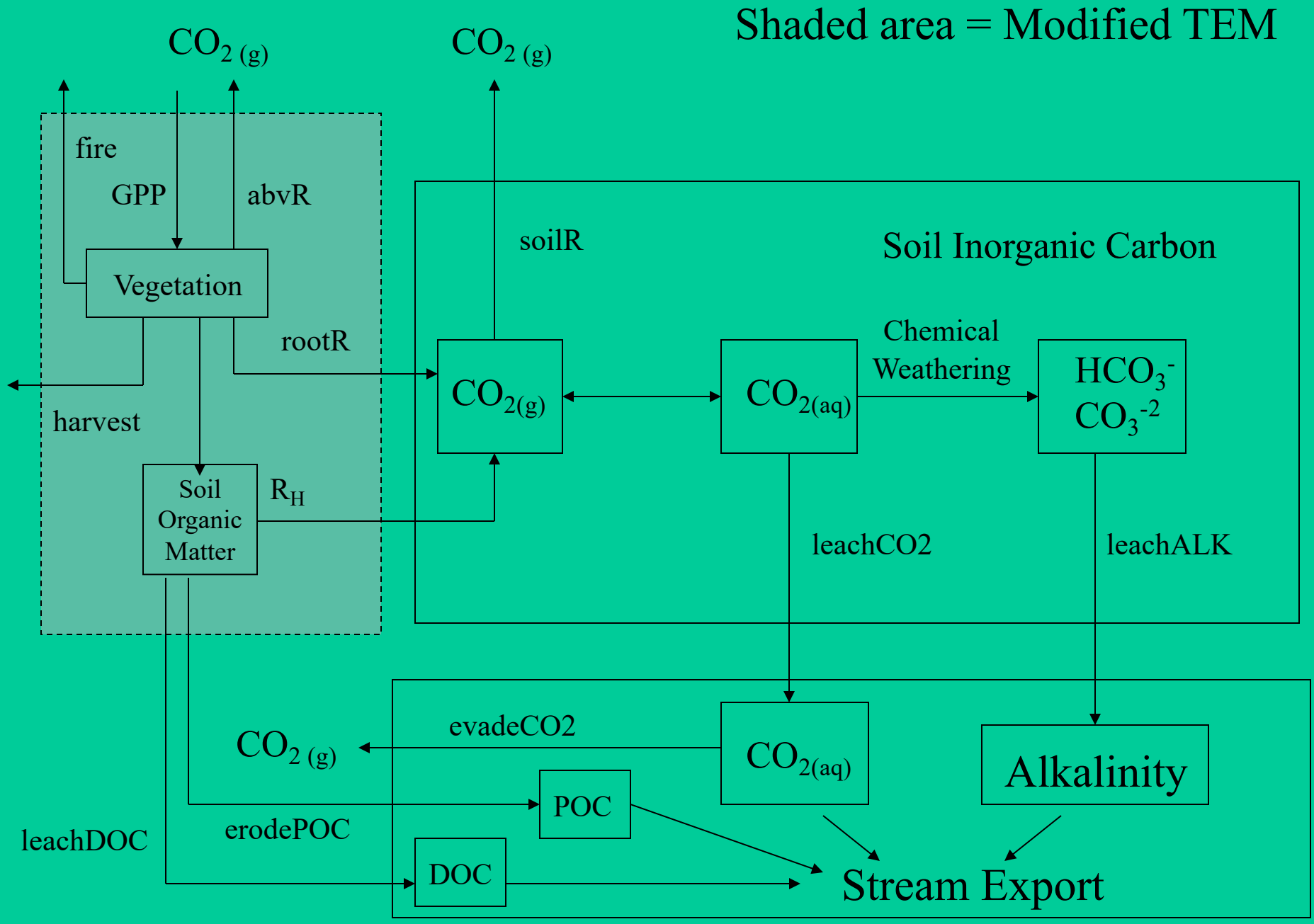
Consumption
= -7 Tg CH_4 yr^{-1}

Net Methane Fluxes
= 49 Tg CH_4 yr^{-1}

(Zhuang et al., 2004GBC)



Tool for Transfer of C from Land to Ocean



Yukon River Project Participants

U. S. Geological Survey:

National Research Program
National Stream Quality Accounting Network
District Offices AK, CA, GA, OR, TX, WI
Alaska Science Center

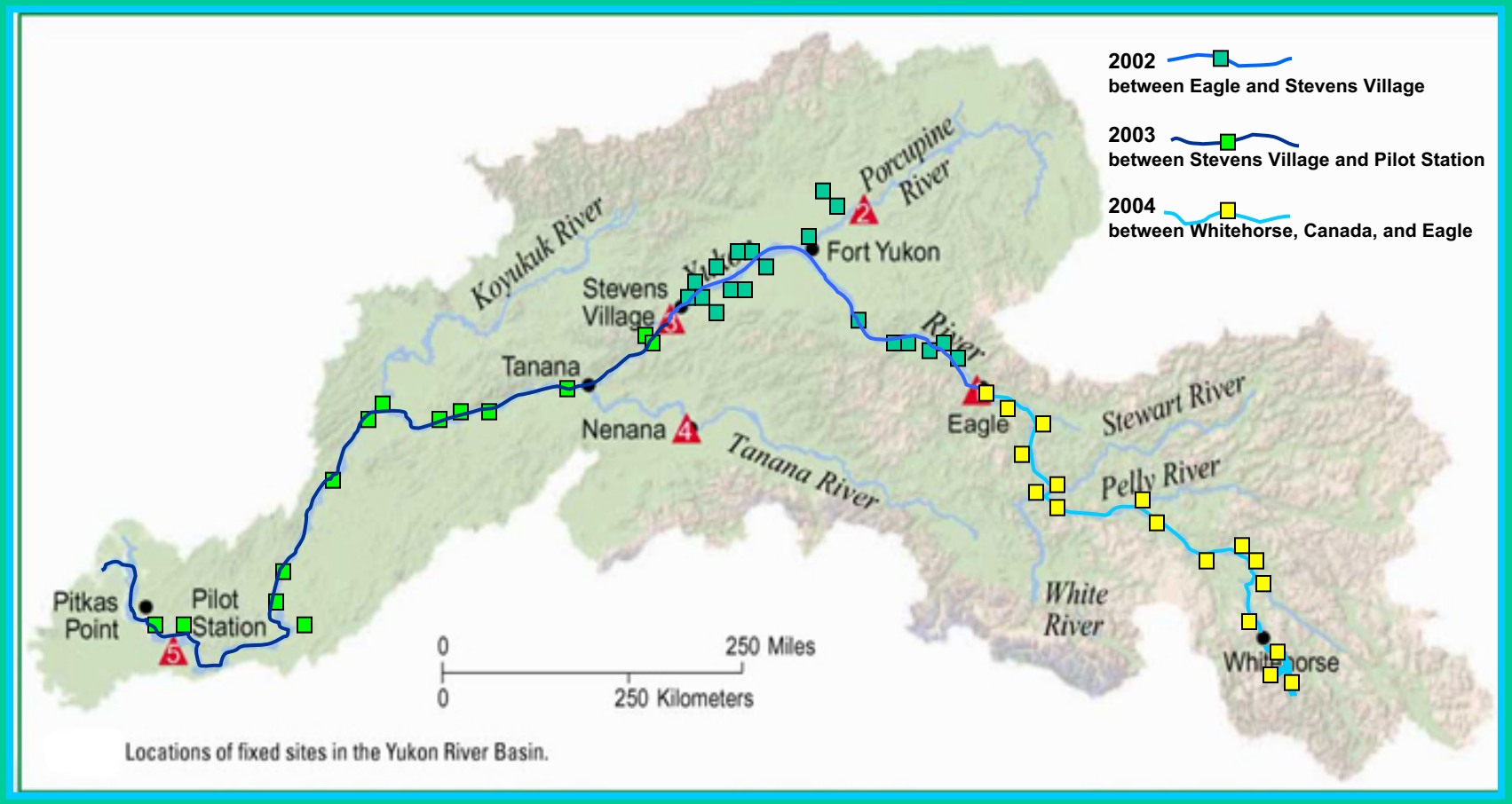
Universities:

Florida State University
University of Southern Mississippi
Yale University

With thanks to:

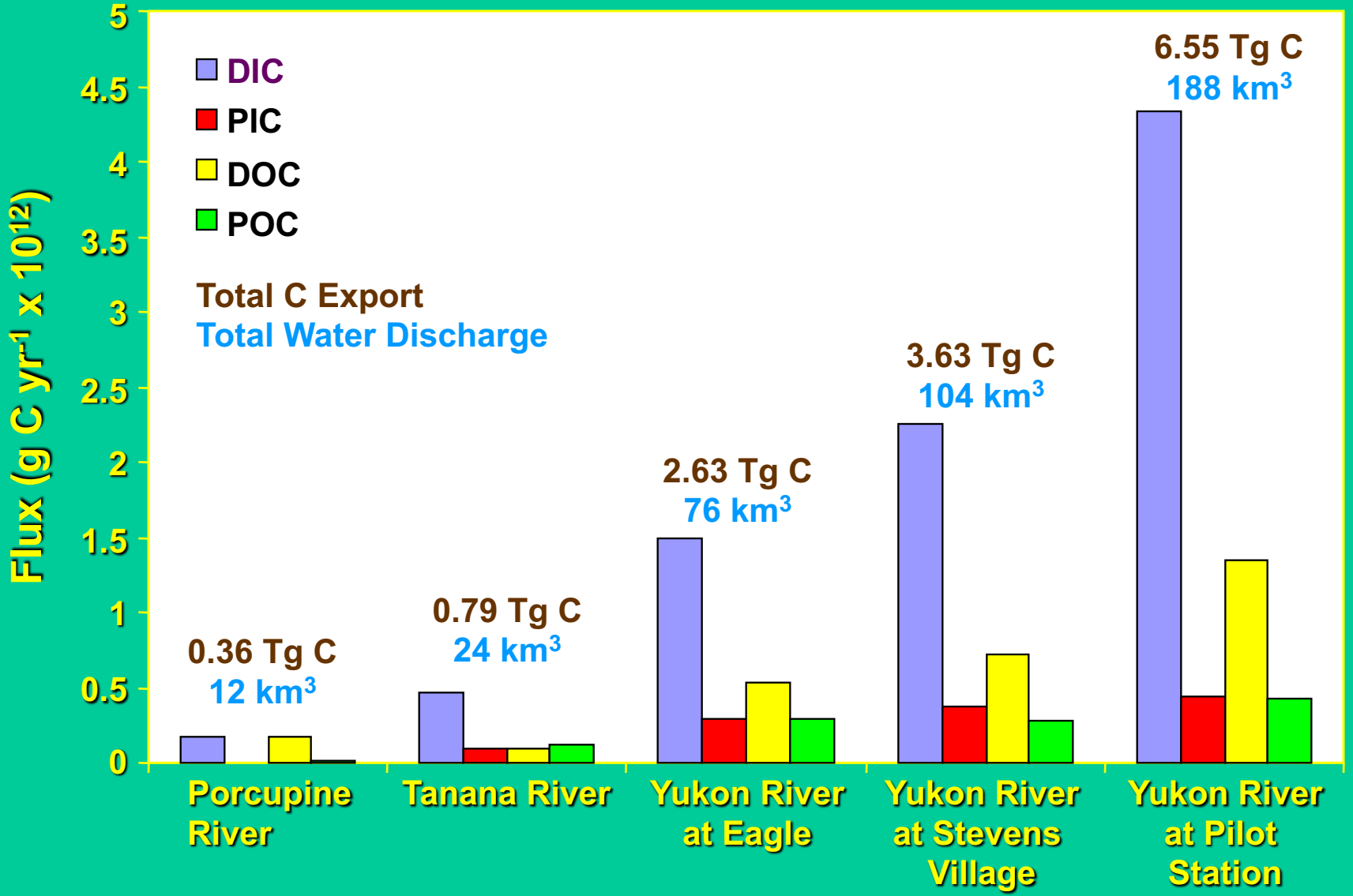
Environment Canada
Water Survey of Canada
Yukon Territorial Government
Alaska Inter-Tribal Council
Alaska Department of Fish and Game
Bureau of Land Management
National Park Service
U S Fish and Wildlife Service
Citizen Volunteers

USGS

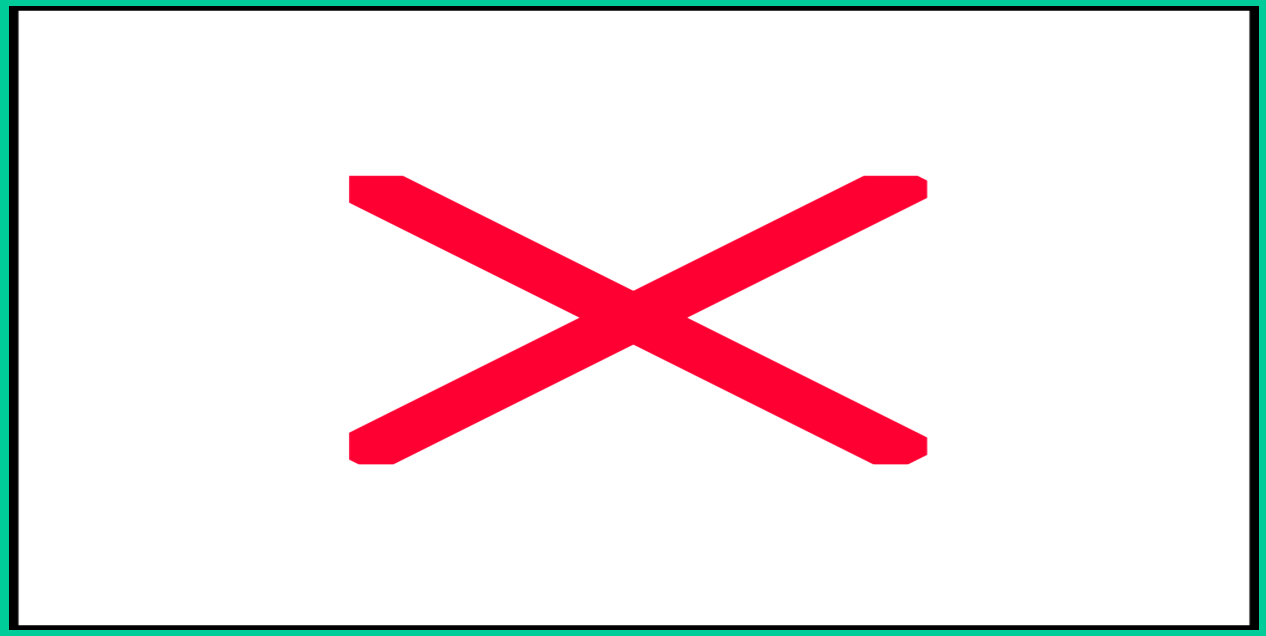


Locations of fixed sites in the Yukon River Basin.

Carbon Flux, Water Year 2002



Annual DOC Leaching from Contemporary Ecosystems in the Yukon River Watershed during the 1990s



0 0.5 1 2 4 8 16 22

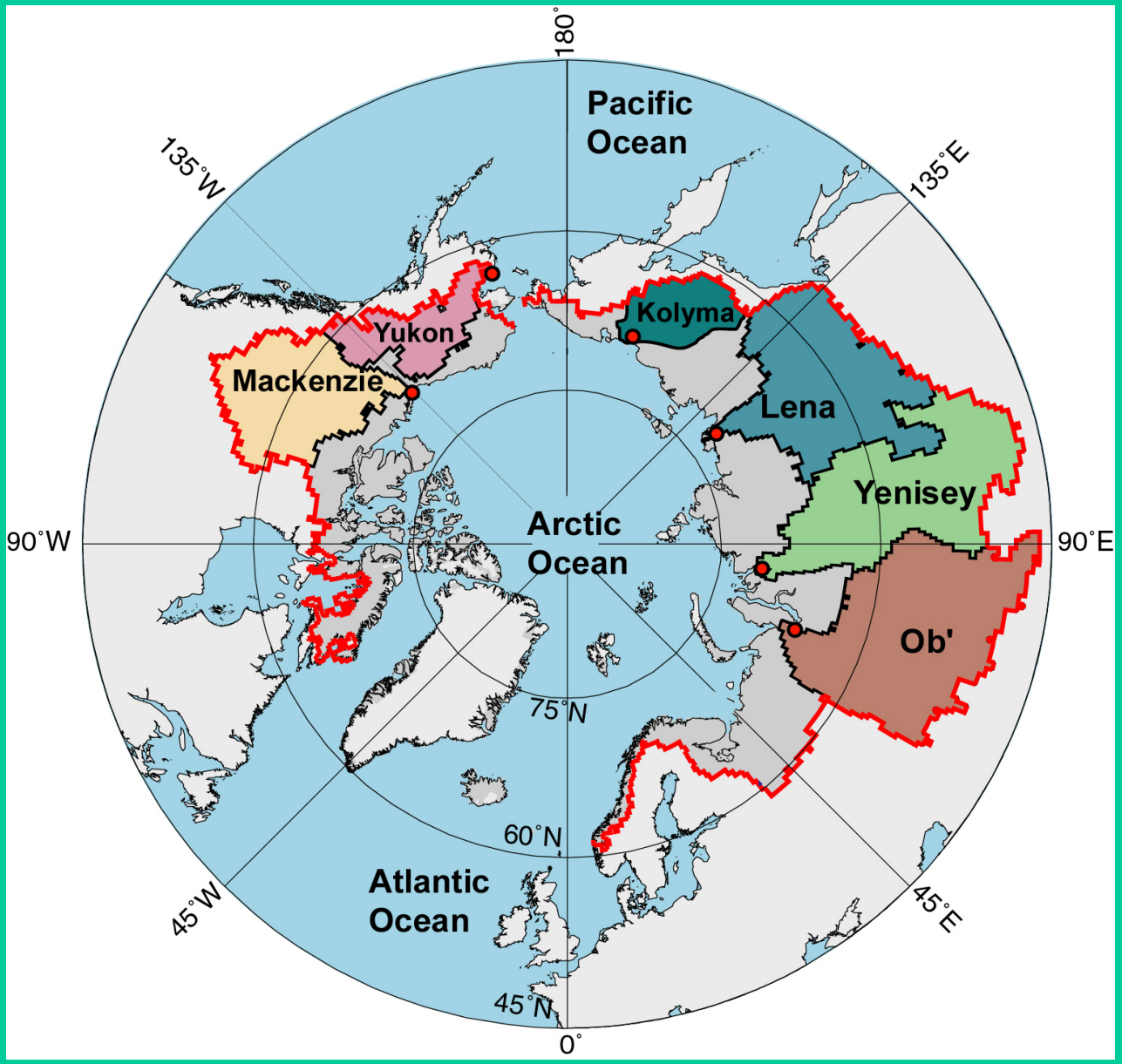
g C m^{-2} yr^{-1}

Total: 1.0 Tg C yr^{-1}

or 1.15 g C m^{-2} yr^{-1}

TEM 6.0

PARTNERS Rivers



River	km^3/y
Mackenzie	308
Yukon	200
Kolyma	132
Lena	525
Yenisey	620
Ob’	404

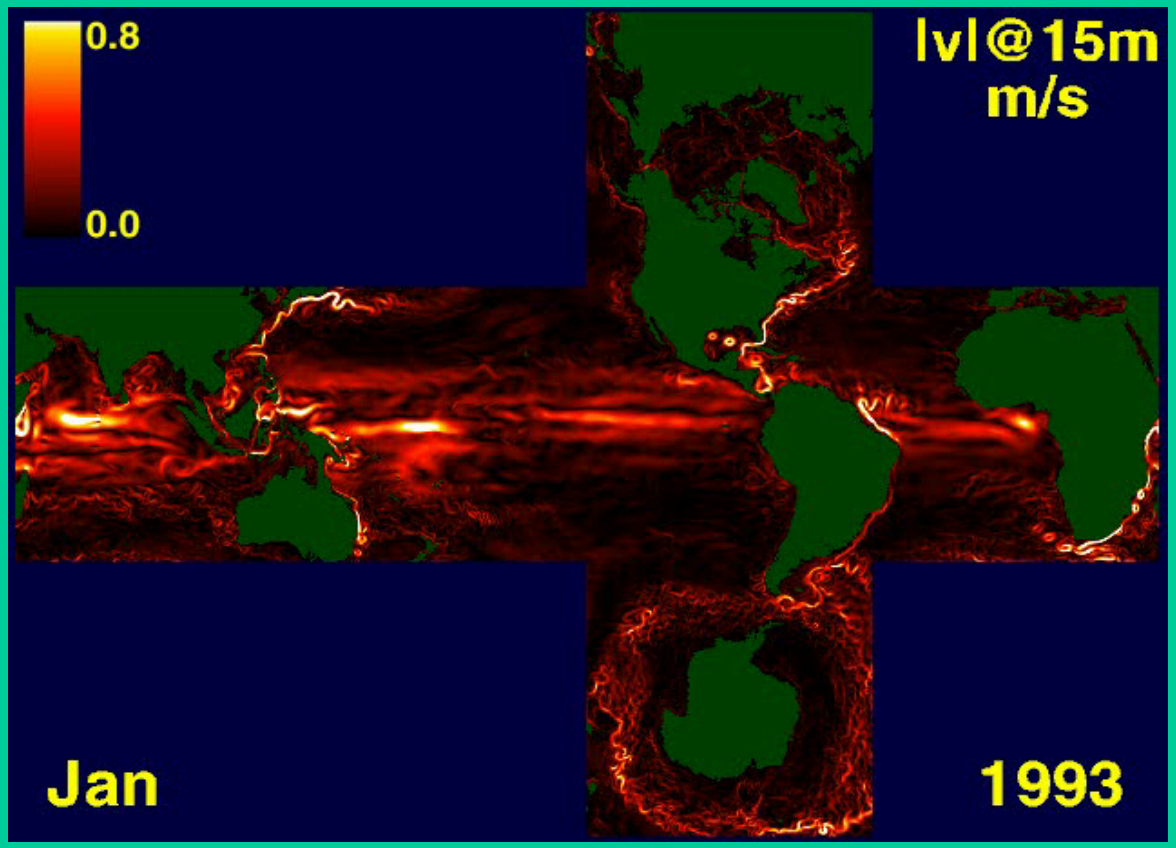
Tools for Ocean C Transfers

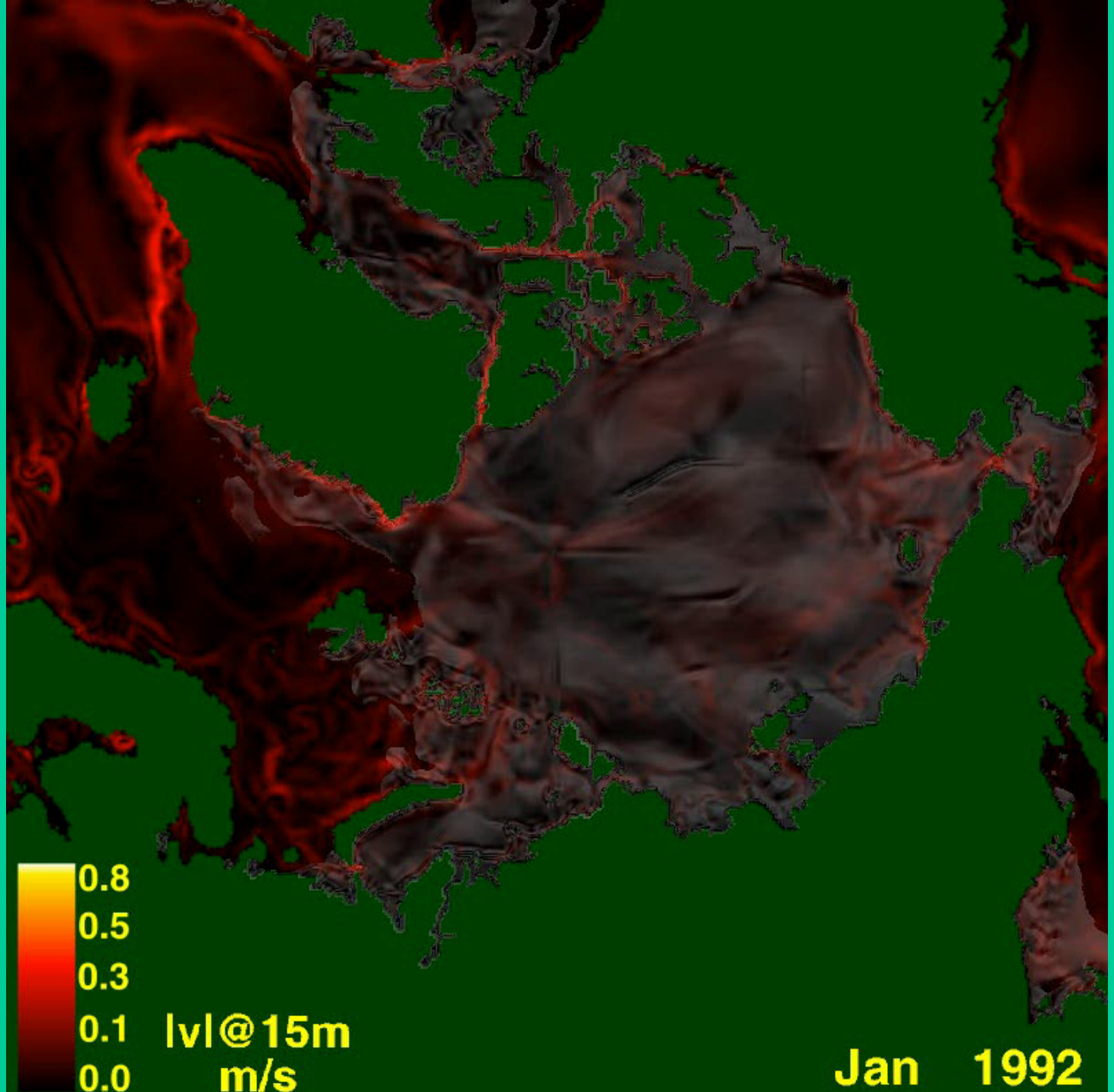
- MIT Ocean Circulation Model
- MIT Ocean Biogeochemistry Model

Physical Framework

- MITgcm
- Global configuration, 1/4^{o} resolution
- Cubed-sphere grid configuration
- Polar oceans resolved, dynamic ice model
- Dimitris Menemenlis (JPL), Chris Hill (MIT) et al.

Physical model – flow speed



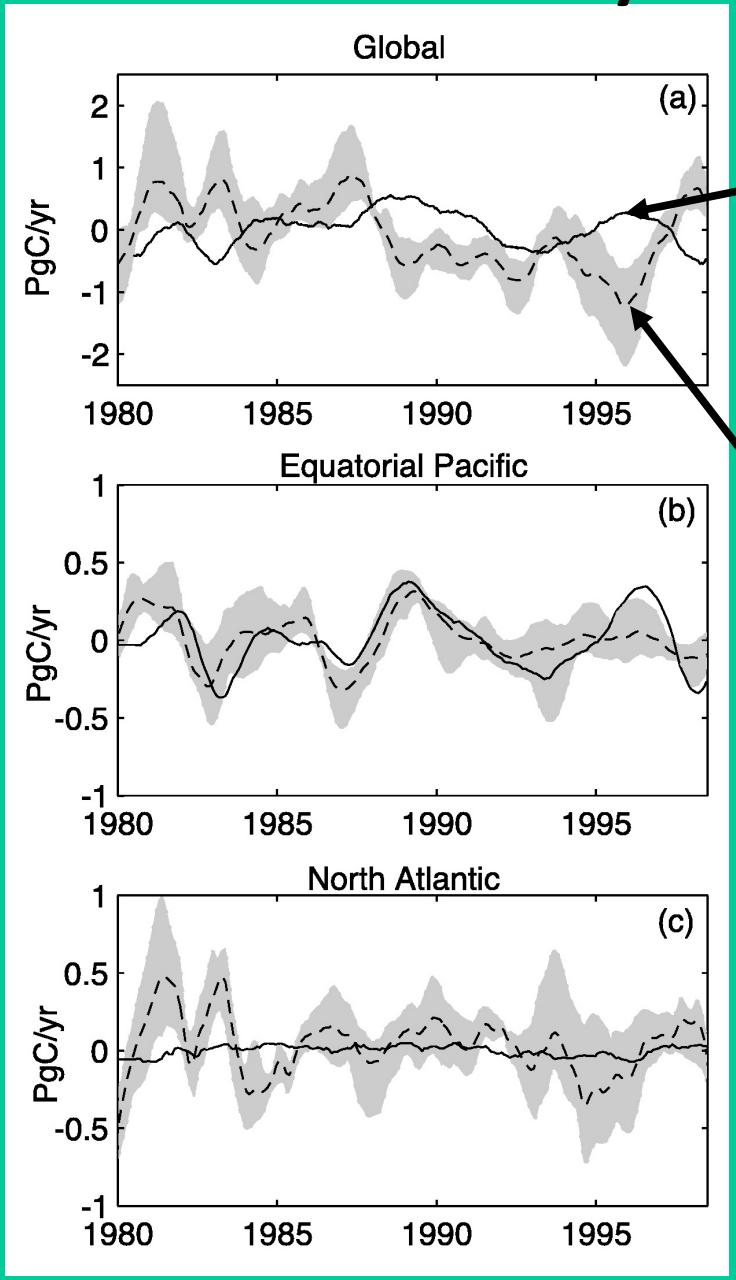

0.8
0.5
0.3
0.1
0.0
|v|@15m
m/s
Jan 1992

Current Ocean Biogeochemistry Model

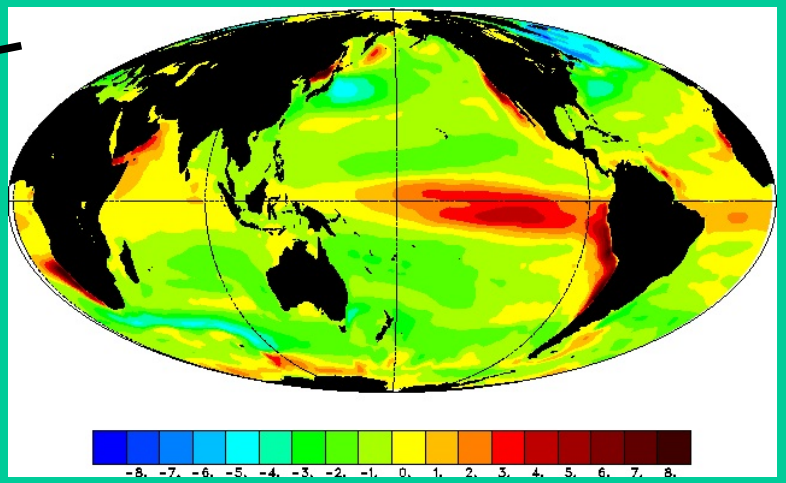
- Explicit C, P, O, Fe, Alk (Ca) cycles
- Prognostic variables DIC, O_2, PO4, DOP, Fe_T, Alk
- Air-sea exchange of CO2, O2
- DOC
  - linked to DOP with fixed stoichiometry
  - No continental sources
  - “Semi-labile”, 6 month lifetime
- Simple parameterization of export production (P, Fe, light limitation)
- Optional explicit ecosystem (2 phytoplankton classes, single grazer, explicit Si cycle)
- Physics – coarse res, generally no Arctic Ocean!

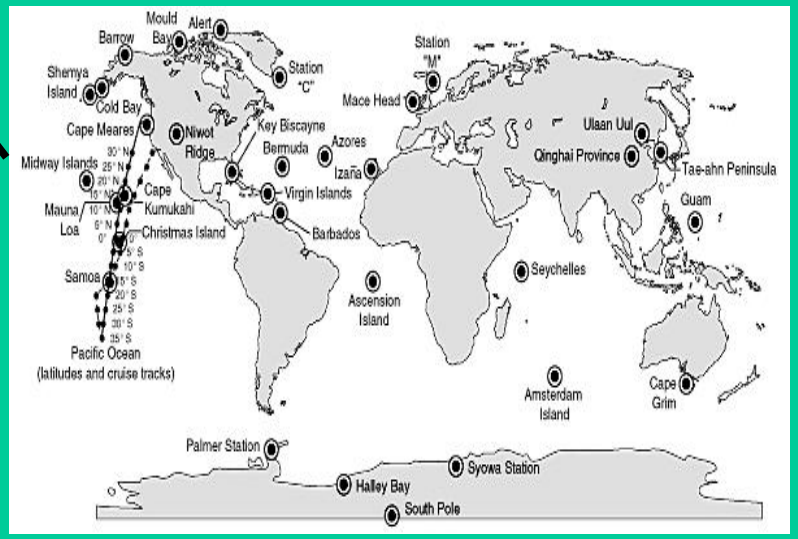
Previous work:

Interannual variability of air-sea CO_2 flux



Ocean model
McKinley et al. (2004)





Atmospheric inverse model
Bousquet et al. (2000)

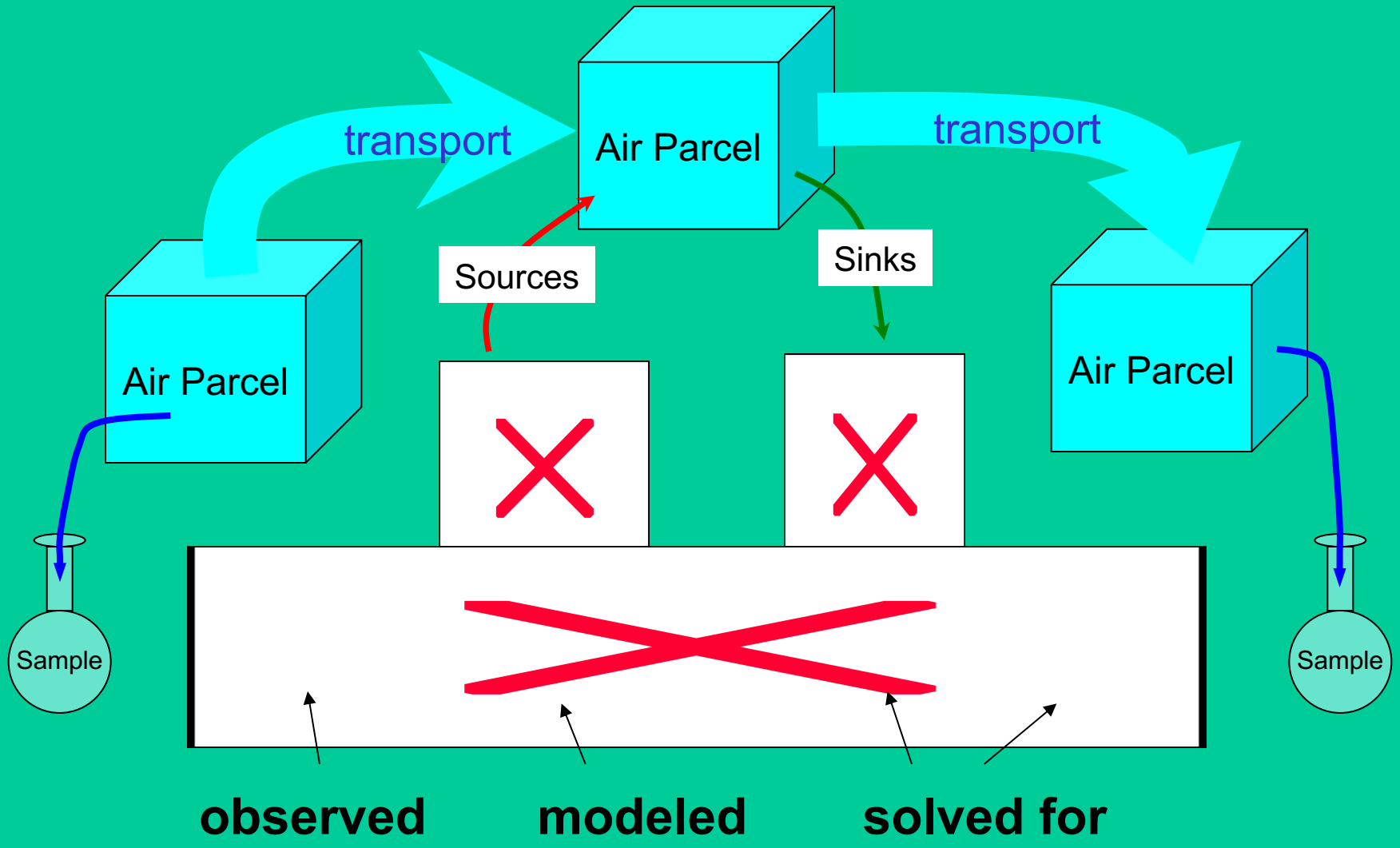
This work: Biogeochemistry

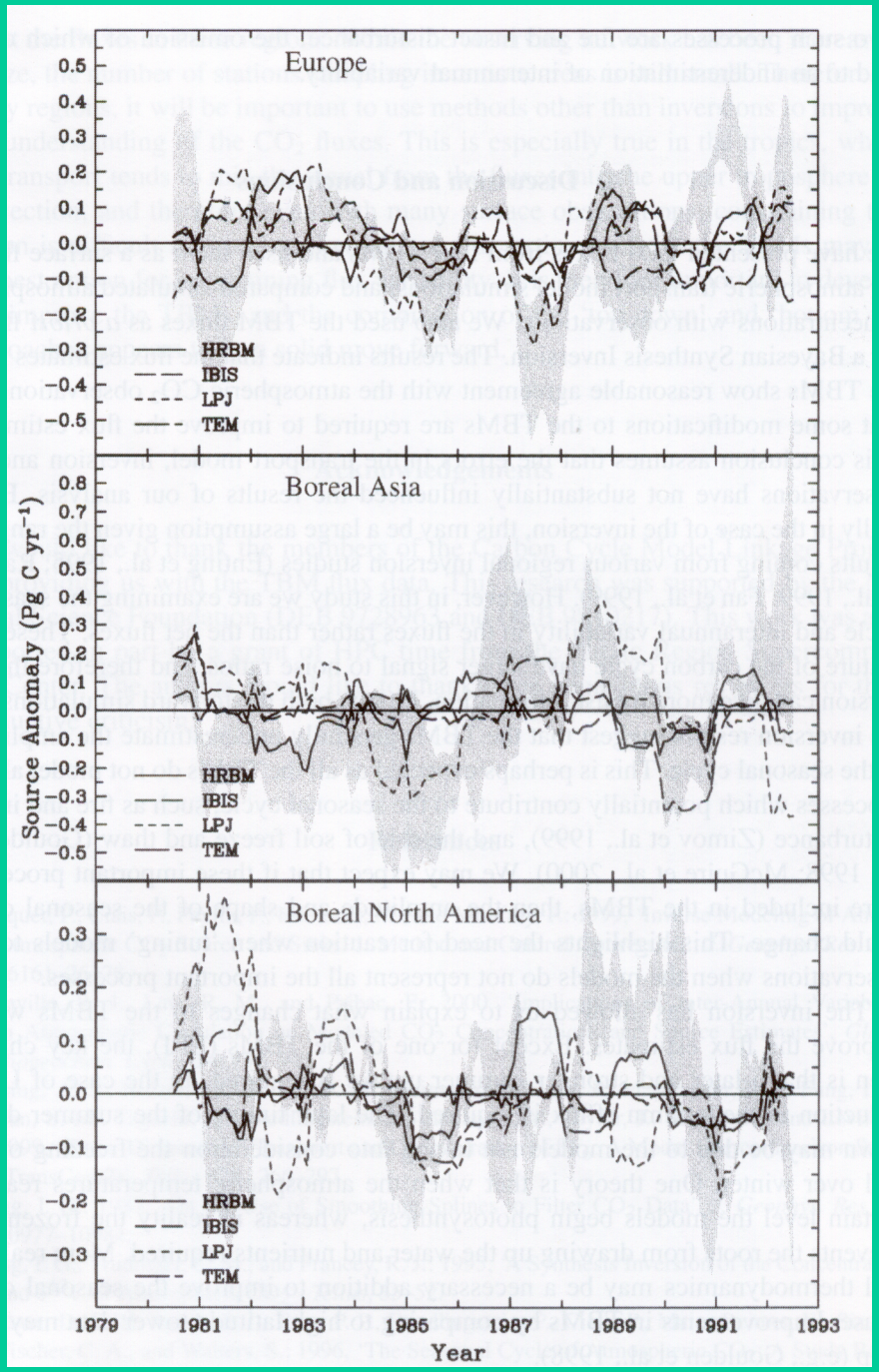
- “Offline” model driven by ECCO2 physics
- Hemispheric configuration
- Estimate air-sea fluxes, distributions, etc 1992 – 2001
- Continental sources/treatment of DOC, DIC
- Explore sensitivity to lifetime of DOC
- Simple export production model (explicit ecosystem)

Tool for Atmospheric Inversions of CO_2 and CH_4

- **MATCH: Model of Atmospheric Transport and Chemistry**

Inverse Modeling

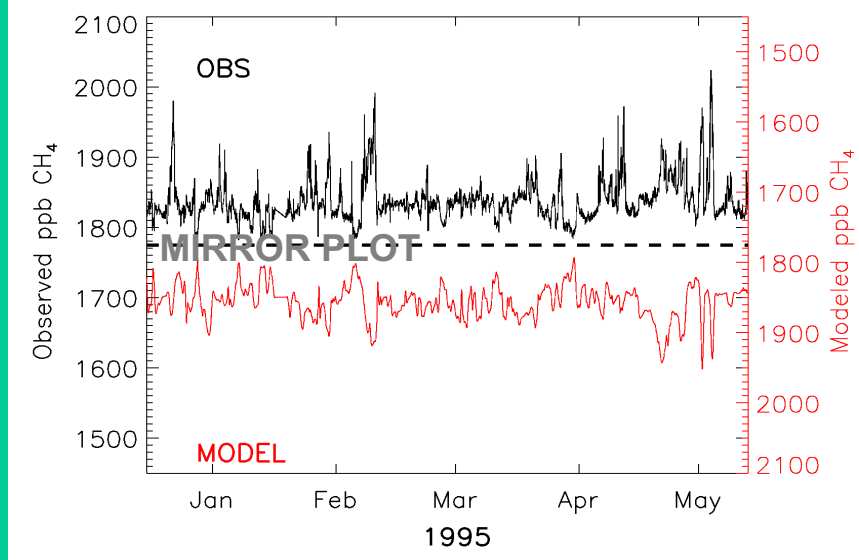


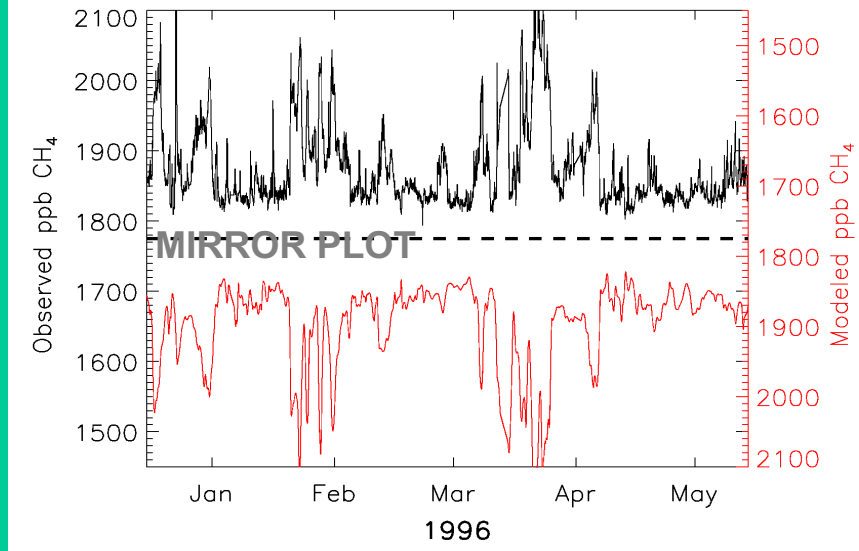


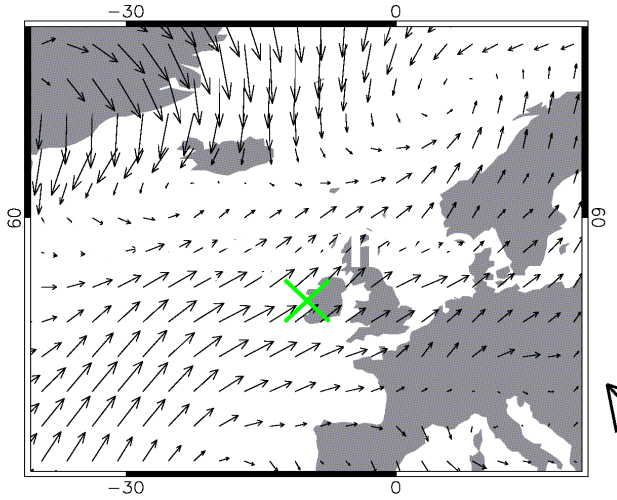
Dargaville, McGuire, and Rayner 2002 (*Climatic Change*)

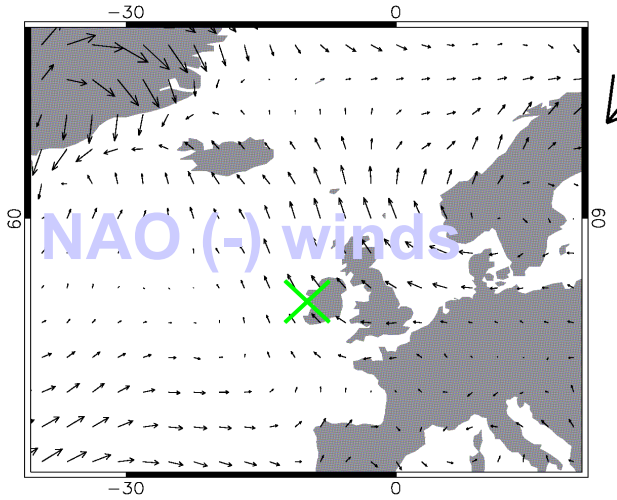
Figure 2. MATCH simulates effect of North Atlantic Oscillation on CH_4

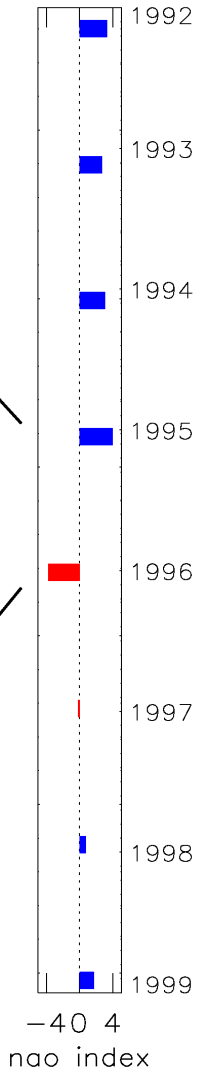
AGAGE observations (red) versus MATCH (black) at MaceHead, Ireland











Ref: Chen & Prinn, 2005; Chen, 2004

Time Line of Research

- First Year – Organize data sets and finish up any necessary model development
- Second Year – Conduct model-data fusion studies with the models
- Third Year – Project Synthesis

Education and Outreach

- *Undergraduate and Graduate Curriculum*
  - Courses
  - MIT Course on Global Climate Change
- *Undergraduate, Graduate, and Postdoc Research*
  - Graduate Students – Purdue
  - MIT – UROP
  - Postdocs – UAF, MIT
- *Public Outreach*
  - Presentations: Policy Meetings/Workshops
  - MIT Global Change Forum
  - MIT Knight Science Journalism Fellows

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