NACP Synthesis Project: Spatial and Temporal Distributions of Sources for non-CO_2 Greenhouse Gases (CH_4, CO, N_2O, SF_6, PFCs,…) in North America

NACP Science Team Meeting, San Diego, CA 16-20 February 2009

Workshop: UCAR CG-1 Conference Room
Boulder, Colorado
22-23 October 2008

Compiled by: S. Wofsy, E. Kort, A. Dayalu, Harvard University

Synthesis Project Participants

Steven C. Wofsy (Harvard University) Chair *	Anna Michalak (U. Michigan) *
Arlyn Andrews (NOAA ESRL) *	Ben Miller (NOAA ESRL) *
Elliot Atlas (U. Miami)	John B. Miller (NOAA ESRL) *
Don Blake (UC Irvine)	Steve Montzka (NOAA ESRL) *
Lori Bruhwiler (NOAA ESRL) *	Thomas Nehrkorn (AER)
Patrick Crill (U. Stockholm) *	Paul Novelli (NOAA ESRL) *
Bob Cook (ORNL)	Gabrielle Petron (NOAA ESRL) *
Archana Dayalu (Harvard University) *	Ron Prinn (MIT)
Ed Dlugocensky (NOAA ESRL) *	Jim Randerson (UCI)
Jim Elkins (NOAA ESRL) *	Matt Rigby (MIT) *
Janusz Eluszkiewicz (AER)	Isobel Simpson (UC Irvine) *
Marc Fischer (LBA) *	Colm Sweeney (NOAA ESRL) *
Wei Min Hao (USFS)	Pieter Tans (NOAA ESRL) *
Adam Hirsch (NOAA ESRL) *	Hanqin Tian (Auburn University) *
Dale Hurst (NOAA ESRL)	Michael Trainor (NOAA ESRL) *
Eric Kort (Harvard University) *	Margaret Torn (LBL)
John C. Lin (U. Waterloo)	Paul Wennberg (Cal Tech) *
Elaine Matthews (NASA GISS) *	Doug Worthy (Environment Canada) *

[*] Attended the workshop 22-23 October 2008 in Boulder, CO

Motivation for the synthesis

The major non-CO_2 greenhouse gases (**CH_4, CO, N_2O**) are a major focus for the NACP, with many fundamental scientific issues unresolved. Knowledge of their spatially and temporally resolved emissions in North America is needed for decision support in the climate change arena.

CH_4 and N_2O together account for almost half of the radiative forcing attributed to CO_2. CO sources affect O_3 and CH_4, thus it is a potent "indirect" Greenhouse gas; also it is a tracer for CO_2 for emissions from mobile sources and biomass fires.

Other gases in this synthesis will include "minor" industrial greenhouse gases (**CFCs; HCFCs; SF_6**) which together account for ~25% of radiative forcing, plus a variety of other species that can help us to understand the budgets of major greenhouse gases: (**COS; C_2H_6; C_2H_2; …)**

The synthesis products will be designed to address societal needs ("decision support") for better quantitative knowledge of greenhouse gas sources in N. America.

The data products of recent and ongoing programs will be the foundation for the results from the synthesis, and the scientists active in these projects will be key collaborators. Each collaborator will have an ownership stake in the products, engendered by participation in the workshop and in the work of the synthesis, and in authorship of the published products.

The steps in the synthesis:

- Determine the scope of the synthesis (species, archive, projects)—*Boulder Workshop, Oct. 2008*

- Develop a comprehensive data base for the target species.

current phase

- Carry out collaborative studies to obtain temporally and spatially resolved budgets for the target species: "the best possible synthesis of atmospheric and ecosystem scale observations".

Deliverables of the Synthesis activity

1. A comprehensive data base in uniform, accessible format.

2. A set of bottom-up source fields for North America, with best possible spatial and temporal resolution, disaggregated by source type—the prior for a Bayesian Inverse Model (or auxiliary data, for Geostatistical Inverse Modeling). *Hanqin Tian*

3. Model—data fusion products giving the "best possible" emissions fields, plus aggregated budgets and inventories for target gases in the NACP domain.

The time line for the Synthesis:

- Determine scope: *Boulder Workshop, Oct. 2008.*

- Data base:

First online version, April 2009.
Final version, January 2010.

- Synthesis projects:

Planning, organization, first steps, April 2009.
First-look and preliminary products, 2nd workshop, September 2009.
Advanced products, January 2010.

Summary of initial data sets to be archived and utilized in the Synthesis .

The data archive for the synthesis project will bring together all possible relevant data sets in one location, with a uniform file format and comprehensive metadata. The time period will extend from 2000 to 2008 and possibly into 2009.

•List of target gases for the archive:

Primary focus—greenhouse gases	Supporting focus—understand the data
CH_4	$^{13}CH_4$; CH_3D ; $^{14}CH_4$
N_2O	H_2
SF_6	COS
PFCs	$CHCl_3$
Banned ozone-depleting chemicals	CO
Halomethanes	C_2H_6
CFC replacements	C_2H_2
	Radon

• Currently active networks:

CCG **(archived at NOAA/ESRL and WMO)**

•*Flask network (global)*

•*Tall tower flask and in situ sensor network (7 sites)*

•*HATS flasks and in situ GCs*

•*Weekly aircraft flask sampling*

contact tower

Environment Canada (archived at WMO and EC)

done!

7 sites across Canada -- flasks + in situ

Irvine latitude network: **(archived at CDIAC)**

final approach!

80 sites, sampled 4x year

AGAGE in situ GC network (archived at CDIAC)

done!

(2 sites* in CONUS plus Barbados off shore)

Data from these networks are publicly available in a variety of locations, up-to-date to varying degrees. **Data from the AGAGE site at Scripps Pier are not yet publicly archived*

Ongoing monitoring in North America

Organization	**Altitude**	**Meas.type**	**Locations**
Environment Canada	Surface stations	Continuous and flasks	7 stations incl. Alert, BERMS, Esteban, Fraserdale,
NOAA Tall Towers (CCCG, HATS)	Profiles in the lowermost PBL	Weekly, Daily flasks; CO_2,CO, CH_4	WLEF, Waco, Maine, 4 others
TCCON	Integrated columns	FTS	WLEF, Ponca
NOAA aircraft	0-7 km	Month/week 2000 prof/ 2 yr	MA, NH, WLEF, MA, CO, others
AmeriFlux	Surface stations	Continuous (CO, CO_2)	MA, oth

need automated flask samplers!

Intensive studies—aircraft

Mission	Altitude	Meas. type	Locations
COBRA-2003	0 - 10 km, ca. 400 profiles	Continuous, flasks	Northern US and S. Canada, May-June
INTEX-A (2004)	0 - 10 km, ca. 200 profiles	Continuous, flasks	US and S. Canada, summer
COBRA-2004	0 - 8 km, ca. 900 profiles	Continuous, flasks	NE US and SE Canada, summer
CLASSIC (2007)	0 - 8 km	Continuous, flasks	Midwest US
START08/pre-HIPPO; ARCTAS May-July 2008; HIPPO Jan 2009	0 – 14 km	Continuous, flasks; DC-8, HIAPER	US Midwest, central/arctic Canada, Alaska

The Non-CO_2 GHG Synthesis data archive will contain merged data sets for these aircraft missions.

Other possible aircraft missions for the archive include:
MILAGRO, TexAQS, California Central Valley, NACP-MCI, Environment Canada flights 2003-05. Ground based measurements and industrial source data may be included also (TBD).

•Data Archive Content and Formats

•Adaptation of the Cook et al. "Best Practices for Preparing Environmental Data Sets" (http://daac.ornl.gov/PI/bestprac.html): ASCII data files, internally documented, conforming names, etc. (*See Wofsy presentation for details.*)

•CCG, HATS and EC will provide flask data with conforming column labels, each record with data for all species from each flask sample (differs from current practice).

•Framework: Synthesis archive will link to specified organization website, ingest data, and automatically make required mods before archiving at ORNL-DAAC.

•Archive content and formats (continued)

- Operable software to be included: data reduction programs; software to create products from input

- Processed data products: aircraft merged data, interpolated budgets/source inventories (e.g. Kriging of surface flux data).

- Data to be made widely available, with limited exceptions. One exception would be for quick-look data provided prior to QA/QC to allow rapid updating of synthesis products.

What is the long term disposition of this archive? Continuation?

•Preliminary List of Syntheses

•Regional N_2O and CH_4 study: build out from constraints provided by global analyses: include DLEM in geostatistical and/or Bayesian framework.

+ Model—data fusion to design optimal locations for tall towers, and locations and frequencies of aircraft.

+ Interpolated budget/inventory products, directly from data/minimal or no priors: from simple (e.g. Kriging), CarbonTracker-CH_4, to very sophisticated (geostatistical).

+ Redo of source distributions:

Industrial sources (CH_4)

Biogenic sources (CH_4, N_2O)

based on plant functional types, bottom up modeling

Leads: Michalak, Wofsy, Sweeney, Hirsch, Andrews & Tian

Participants in the Regional N_2O and CH_4 study (preliminary):

Arlyn Andrews (NOAA ESRL) -- tall tower data, inversions using tower data

Lori Bruhwiler (NOAA ESRL) -- CarbonTracker(R)--Methane intersections

Patrick Crill (U. Stockholm) -- entrainment of surface flux dagta

Archana Dayalu (Harvard University) -- data archive, QA/QC and synthesis

Ed Dlugocensky (NOAA ESRL) -- Network CH_4 data

Geoff Dutton -- HATS network data

Jim Elkins (NOAA ESRL) -- HATS network and synthesis

Janusz Eluszkiewicz (AER) -- transport and STILT development

Marc Fischer (LBA) -- California and ARM data

Adam Hirsch (NOAA ESRL) -- inverse analysis, interactions of large and small scales

Eric Kort (Harvard University) -- STILT application, aircraft data

John C. Lin (U. Waterloo) -- STILT

Anna Michalak (U. MIchigan) -- geostatistical and Bayesian frameworks

Thomas Nehrkorn (AER) -- transport

Gabrielle Petron (NOAA ESRL) -- source distribution

Matt Rigby (MIT) -- global context

Michael Trainor (NOAA ESRL) -- application of aircraft data (intensive)

Colm Sweeney (NOAA ESRL) -- application of aircraft profiles, overall synthesis

Hanqin Tian (Auburn University) -- Gridded products from DLEM and related forcing data

Paul Wennberg (Cal Tech) -- application of FTS data

Doug Worthy (Environment Canada) -- application of Canadian data; Canadian sources

•Candidate Syntheses (continued)

• **Multiple simultaneous species, model—data fusion emissions and inventories:** inverted/optimized simultaneously: CFCs/ HCFCs/ $CHCl_3$, etc [ ]; systematic testing for footprints/ transport ; attribution of biomass fire sources … .

Leads: Montzka, Petron, Hurst

• **Special data project: Footprint files and driver data:**

a) archived particle file and generic code to overlay footprints on any flux map to obtain ΔC, effectively providing to the whole science community high-resolution LPDM capability for selected locations.

b) DLEM input data and model output layers.

Leads: Harvard, NOAA, ORNL

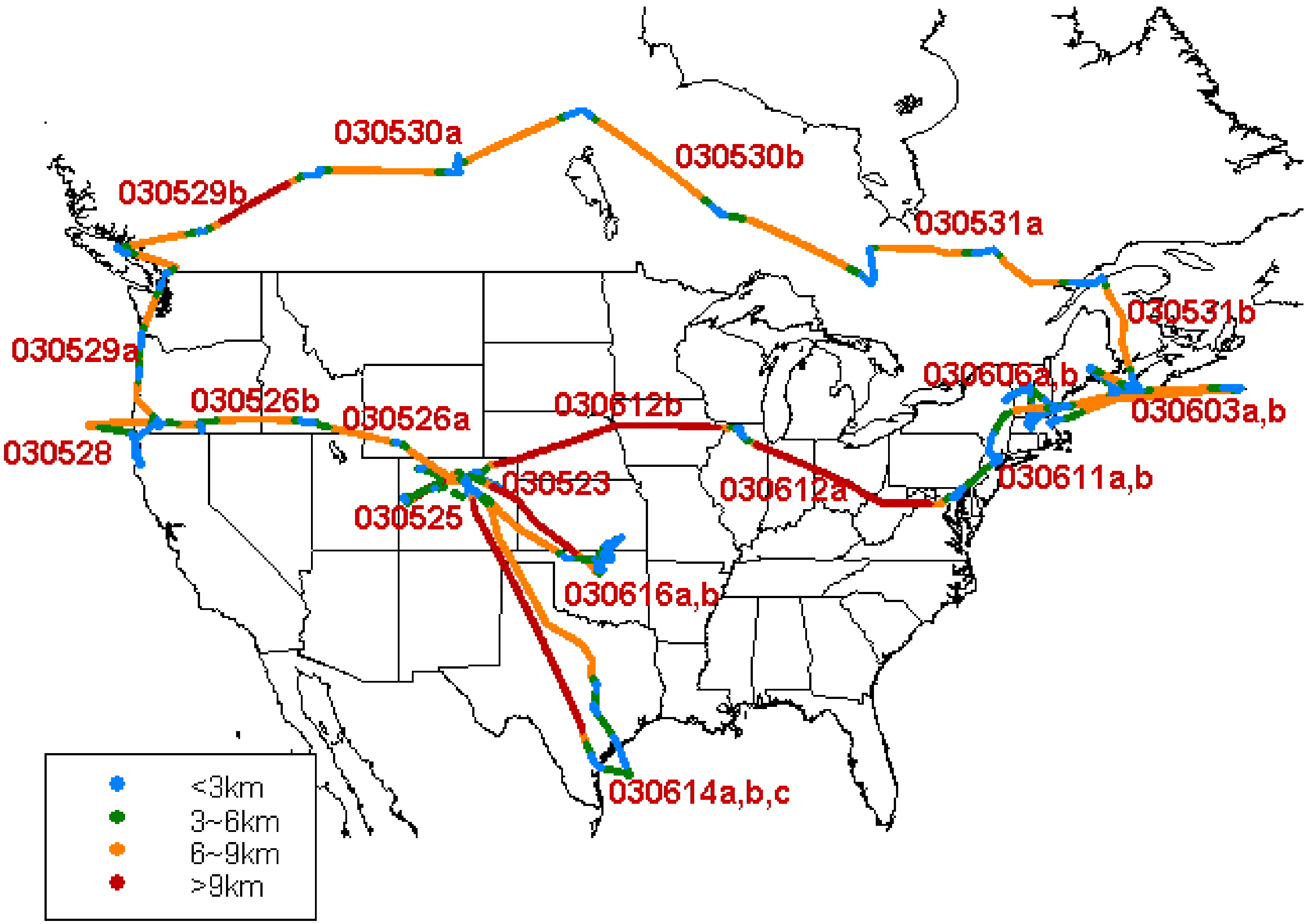
Methane and Nitrous Oxide in North America: Using an LPDM to Constrain Emissions

Eric Kort
kort@fas.harvard.edu

Non-CO2 Workshop

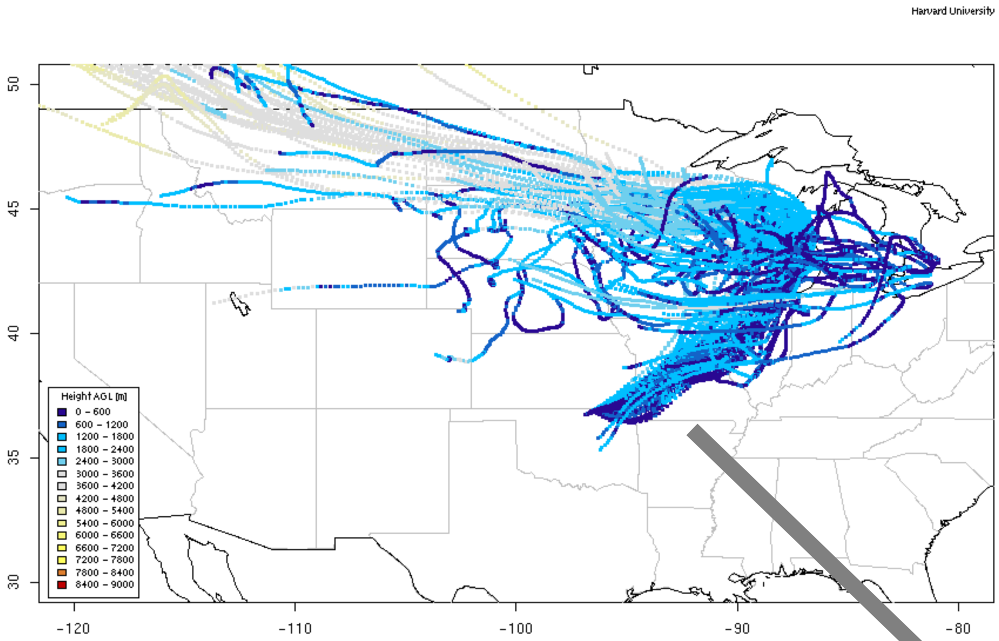
October 23, 2008

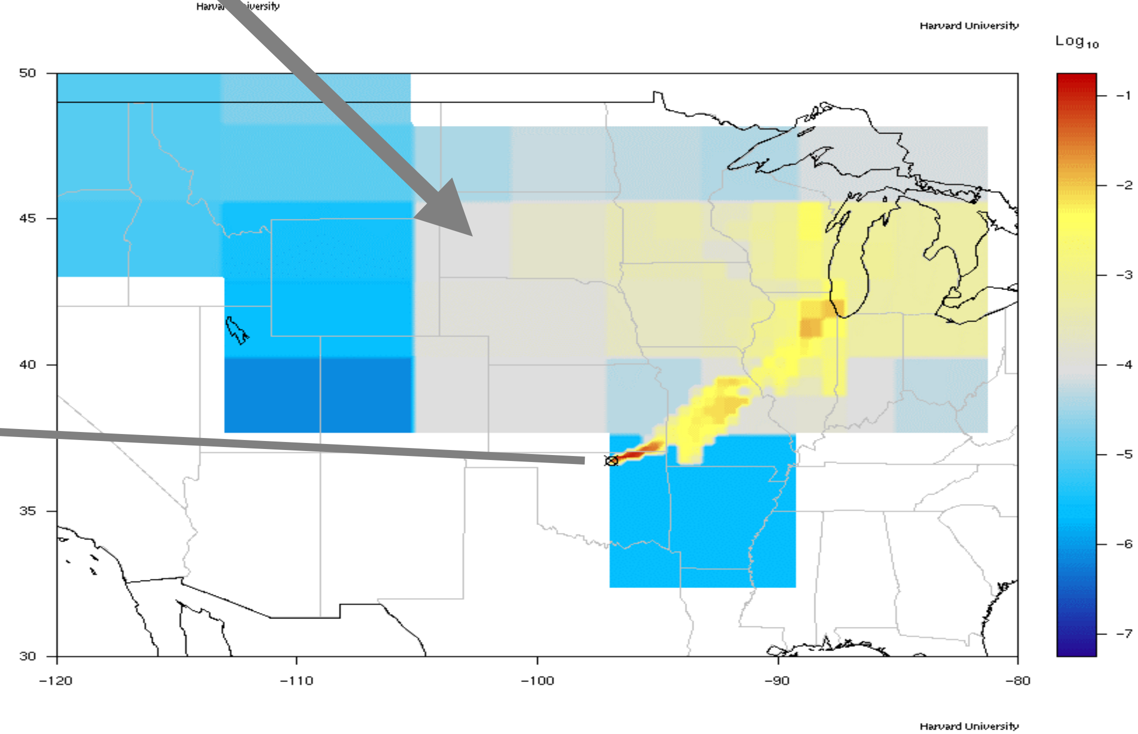
Case Study- COBRA-NA 2003

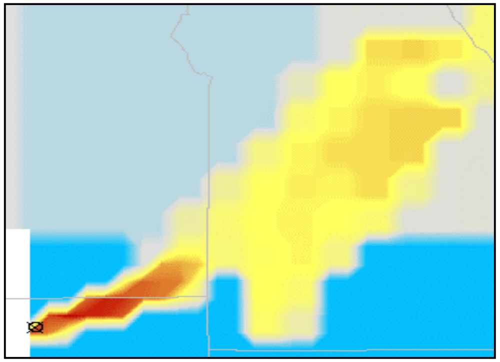


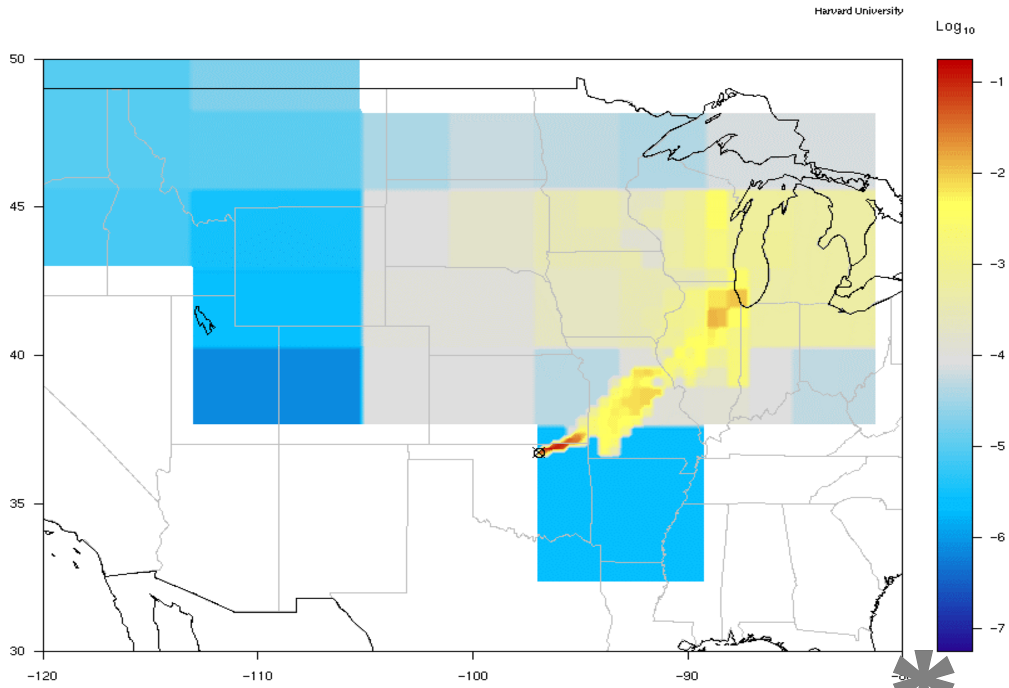
- ~300 flasks measured @ NOAA/Boulder, UND Citation II, 23 May to 28 June 2003

Trajectories to Footprint

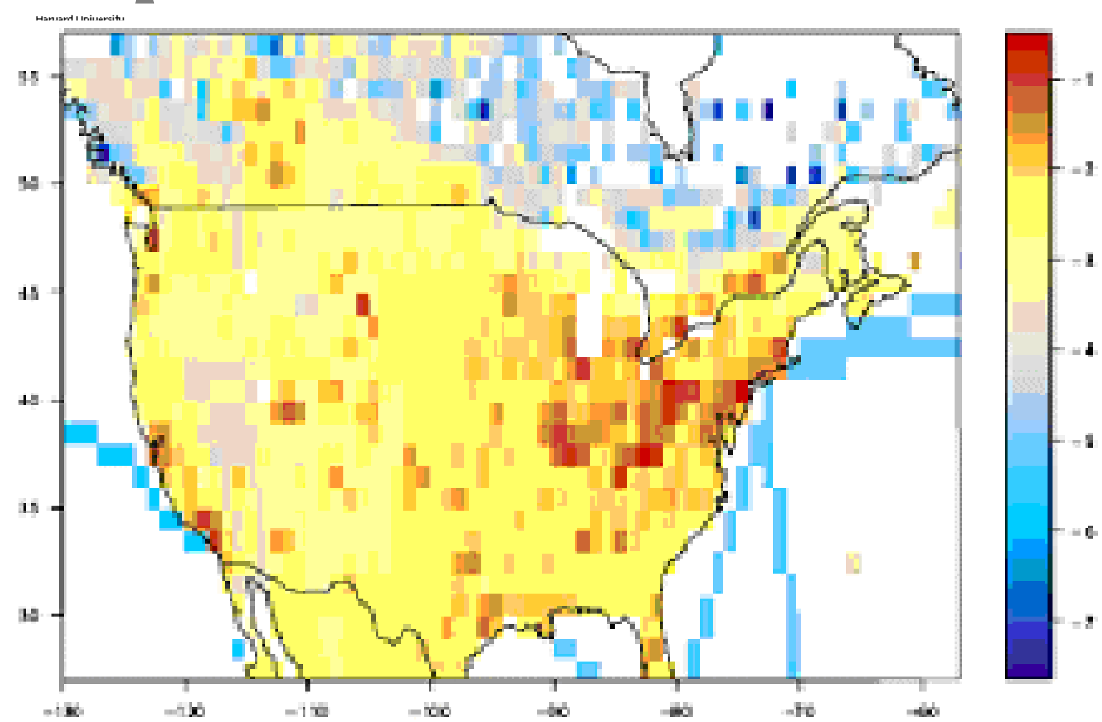








Footprint *
Prior Emission
Field (EDGAR)

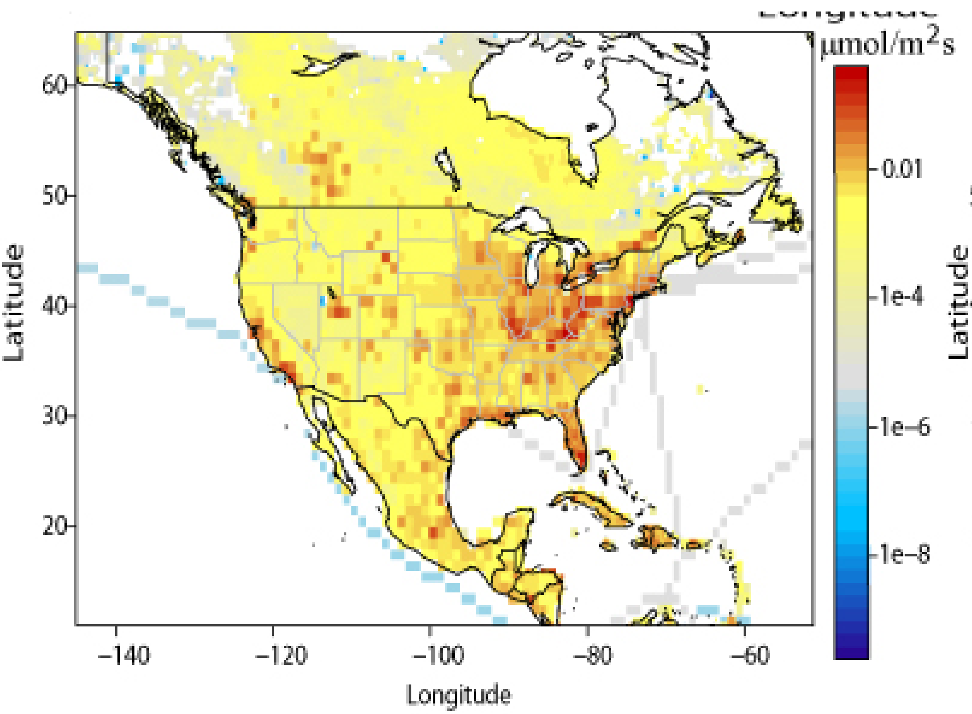


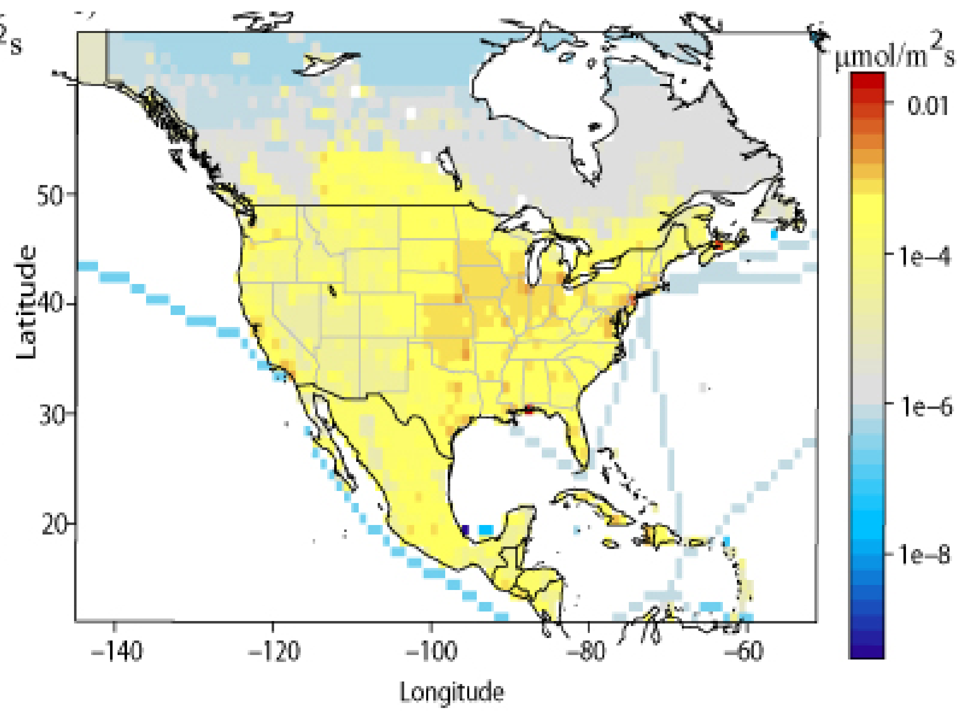
Result =
Enhancement of gas
at measurement
point due to source

Prior Emissions Fields

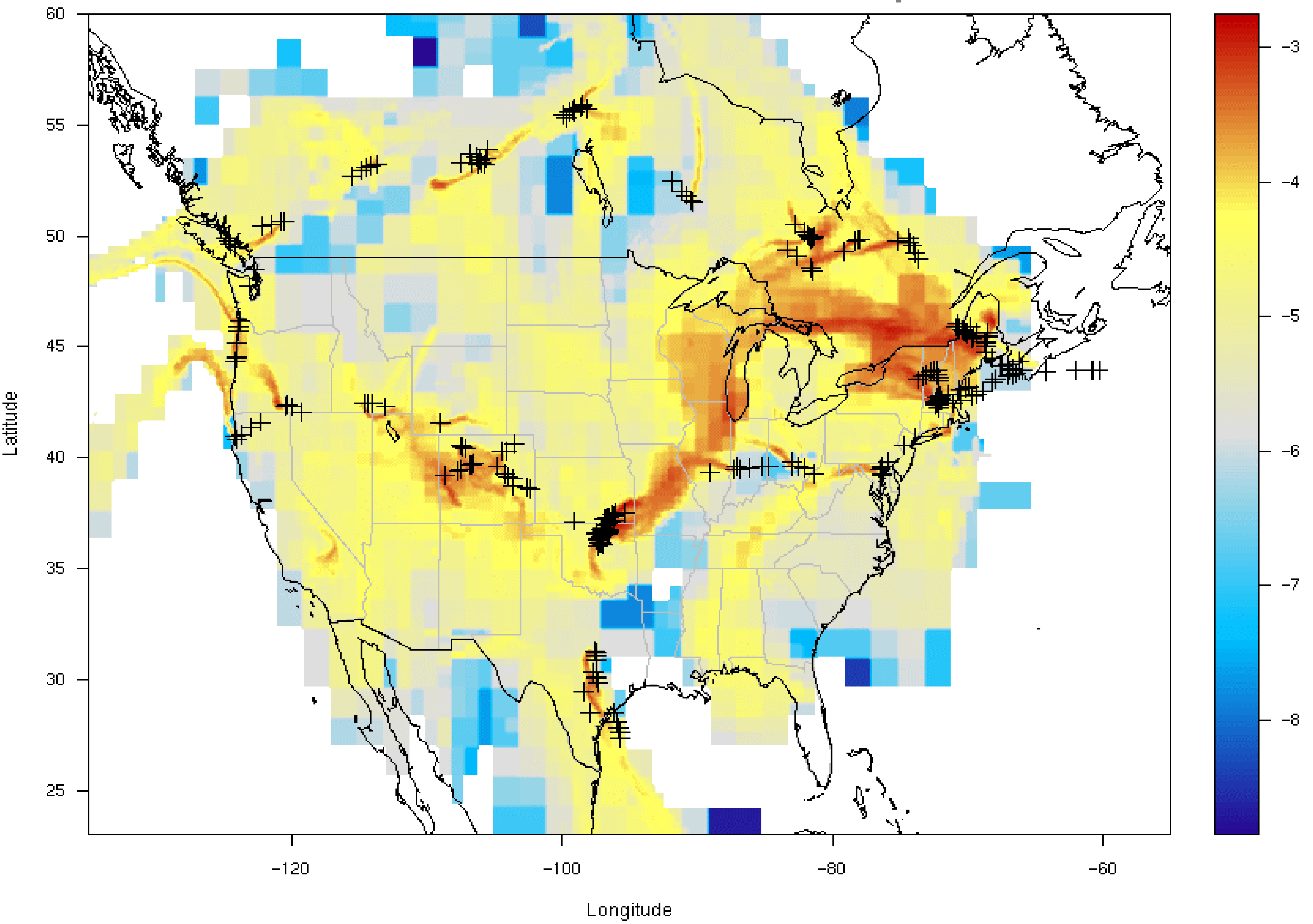
- Methane
  - Anthropogenic- EDGAR32FT2000
  - Biogenic- Jed Kaplan wetland inventory
- Nitrous Oxide
  - Anthropogenic- EDGAR32FT2000
  - Anthropogenic & Biogenic- GEIA

FIRES

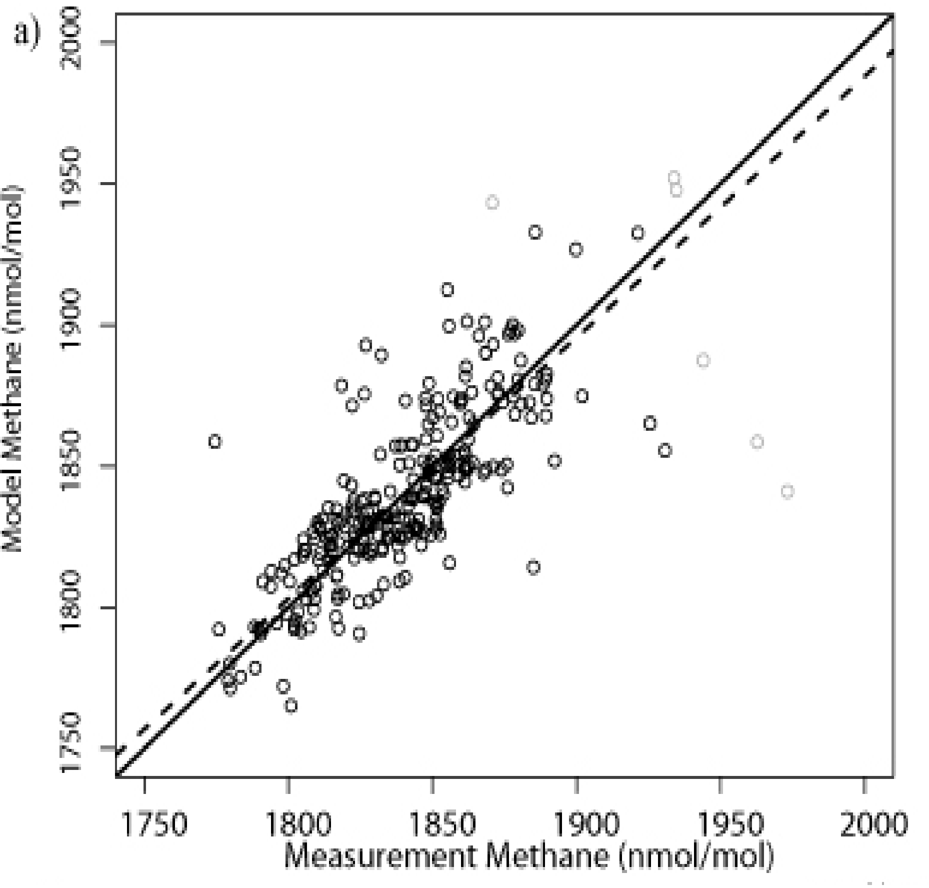


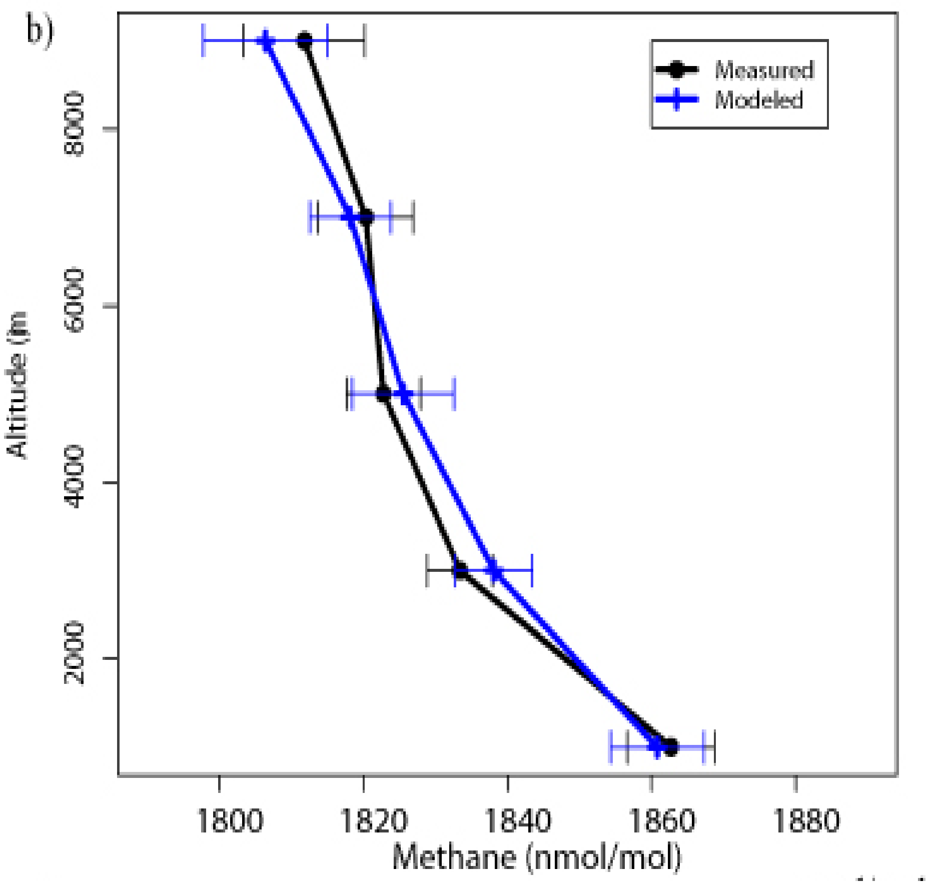


Measurements- Footprint



Results- Methane





Slope: 0.924 ± 0.13

Scaling Factor: 1.08 ± 0.15

Note: Prior Emissions Field
EDGAR32FT 2000 & JK wetland

Prototype CarbonTracker-CH_4: Priors

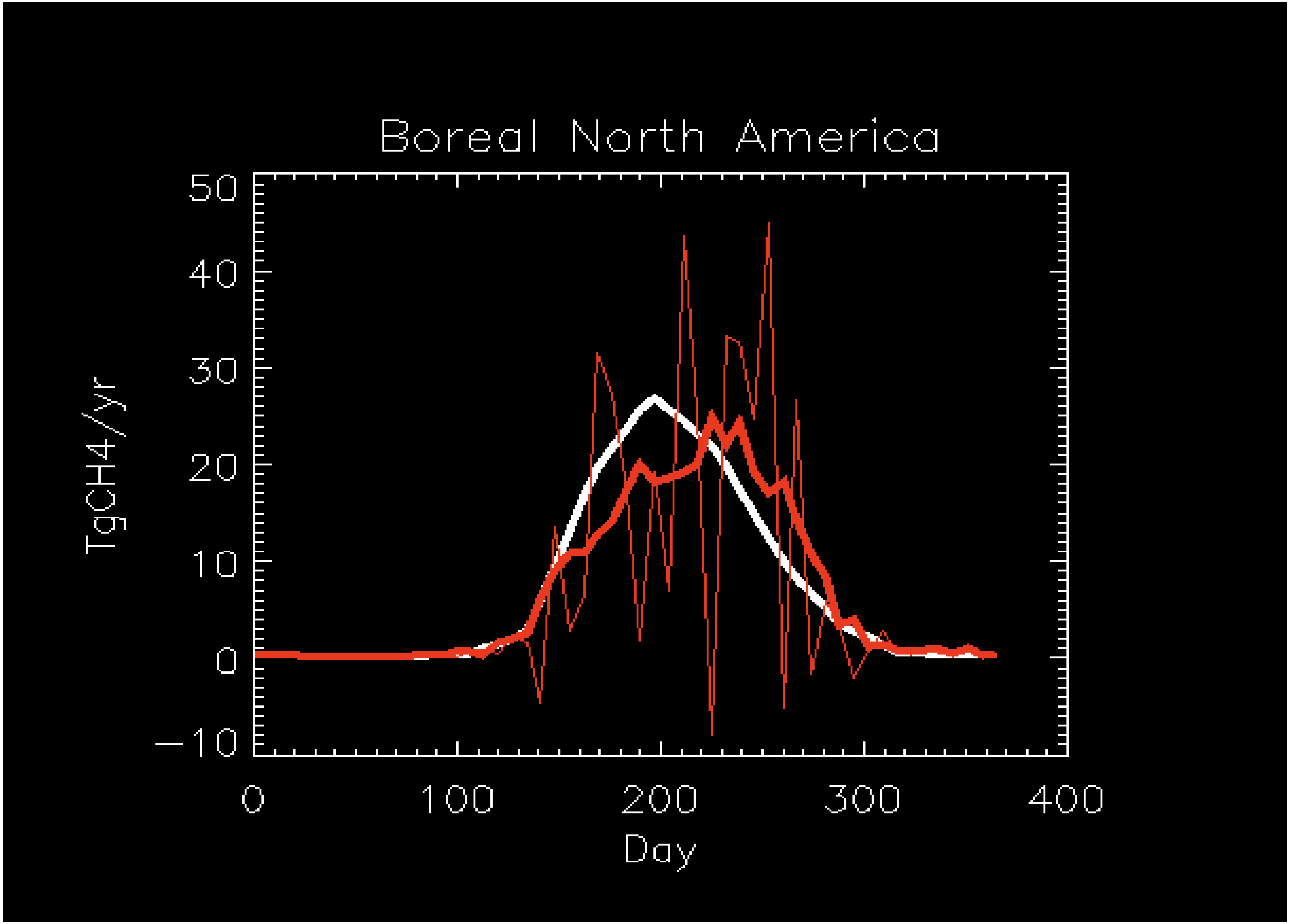
***Bergamaschi et al. (2002)* sources**

- **Large region inversion using network obs.**
- **Coal, Oil/Gas**
- **Enteric Fermentation, Wild Animals, Termites**
- **Rice, Wetlands, Biomass Burning**
- **Waste**
- **Soil Uptake, Oceans**

Photochemical Loss

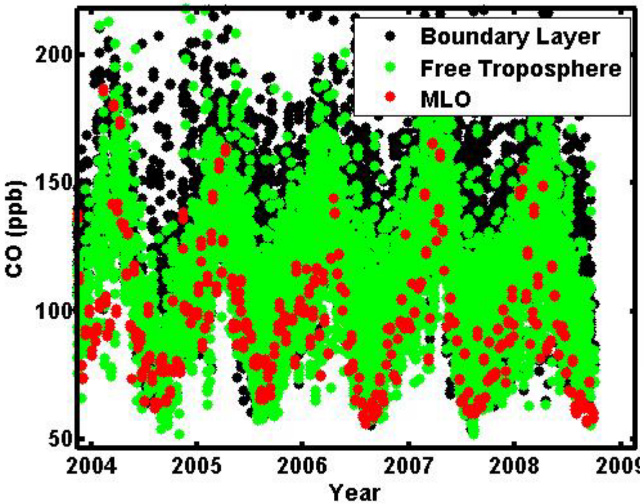
- **Repeating Seasonal Cycle, Optimized Using CH_3CCl_3**

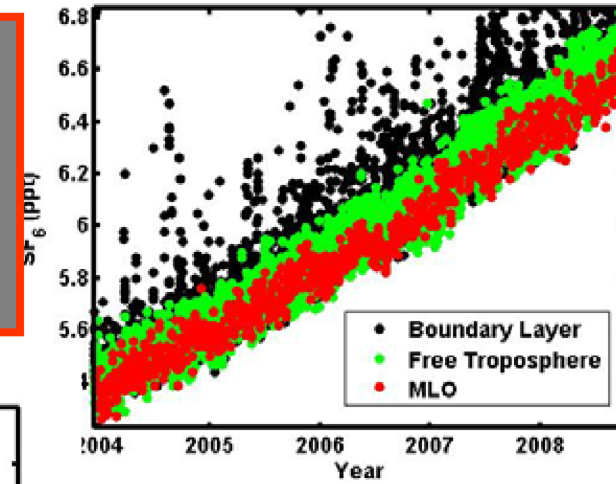
Emissions from Wetlands from CTracker-CH_4

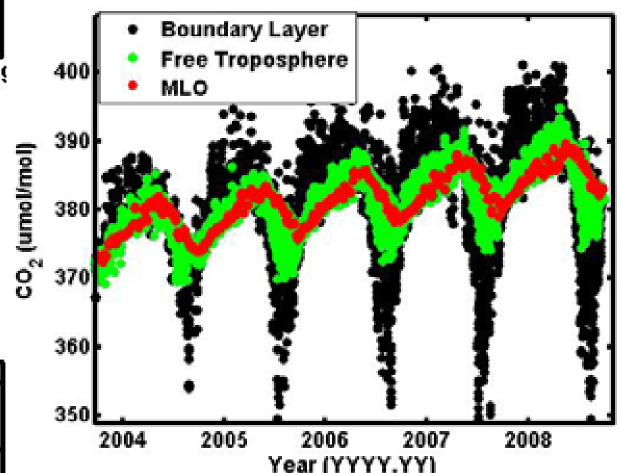


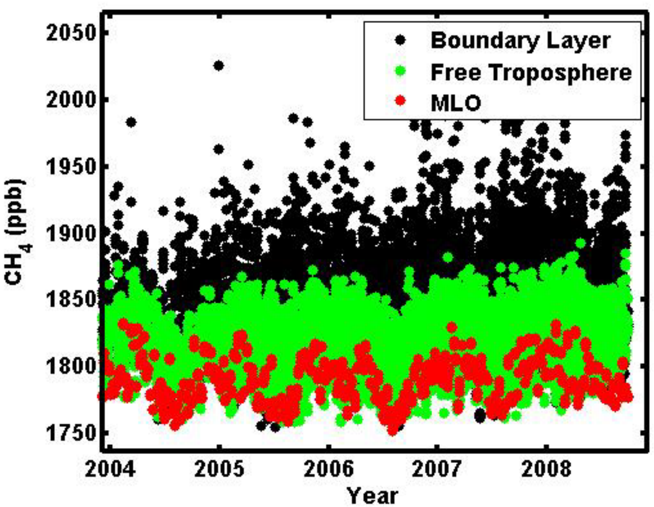
Vertical Profile Observations from NOAA CCG

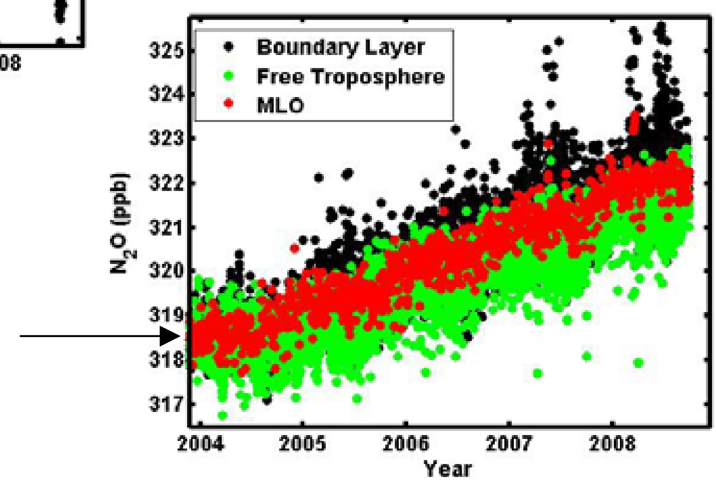
Colm Sweeny

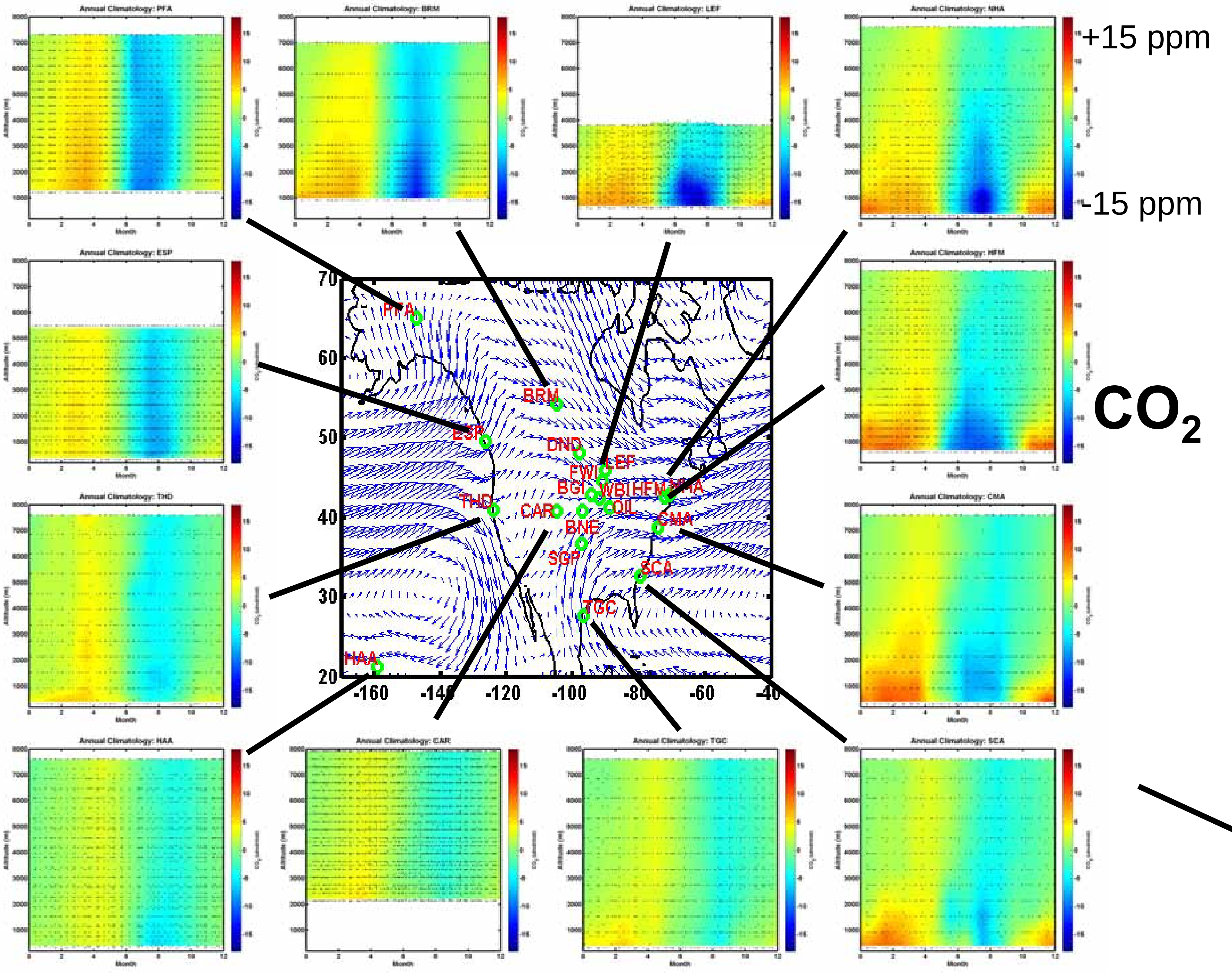












+15 ppm
-15 ppm
CO2
Annual Climatology: PFA
Annual Climatology: BRM
Annual Climatology: LEF
Annual Climatology: NHA
Annual Climatology: ESP
Annual Climatology: HFM
Annual Climatology: THD
Annual Climatology: CMA
Annual Climatology: HAA
Annual Climatology: CAR
Annual Climatology: TGC
Annual Climatology: SCA
PFA
BRM
ESP
DND
LEF
FWI
BGI
WBI
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OIL
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SGP
SCA
TGC
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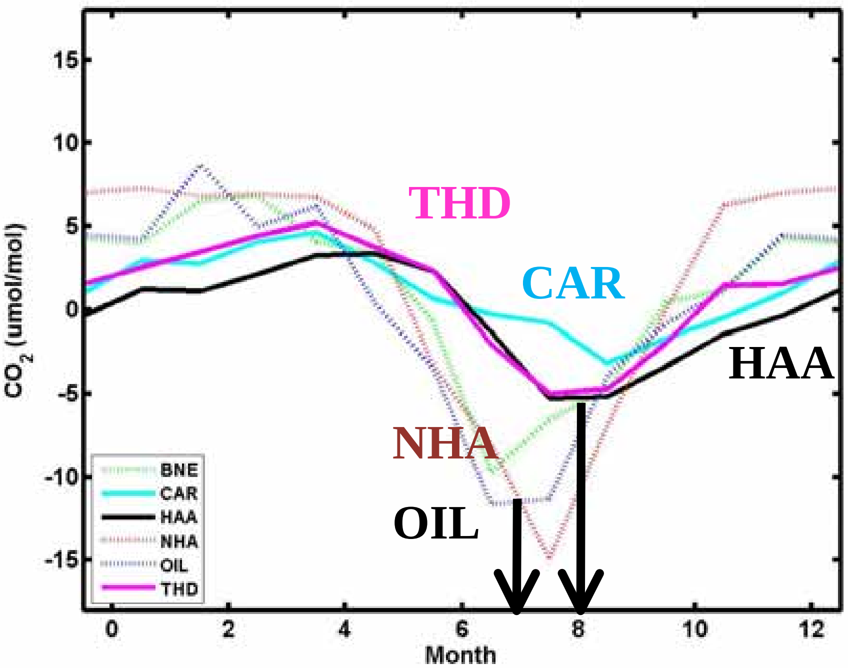
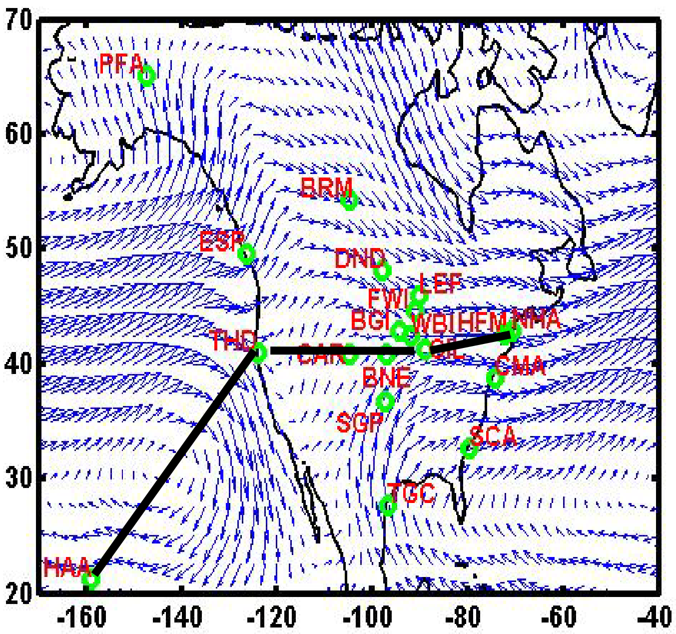
-160
-140
-120
-100
-80
-60
-40

West → East Transect



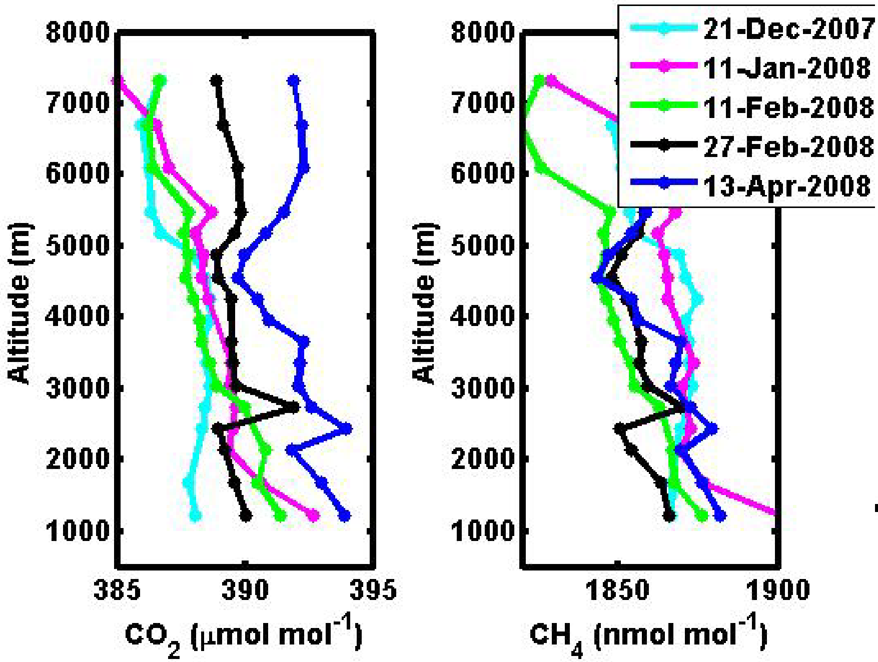


lagged by one month

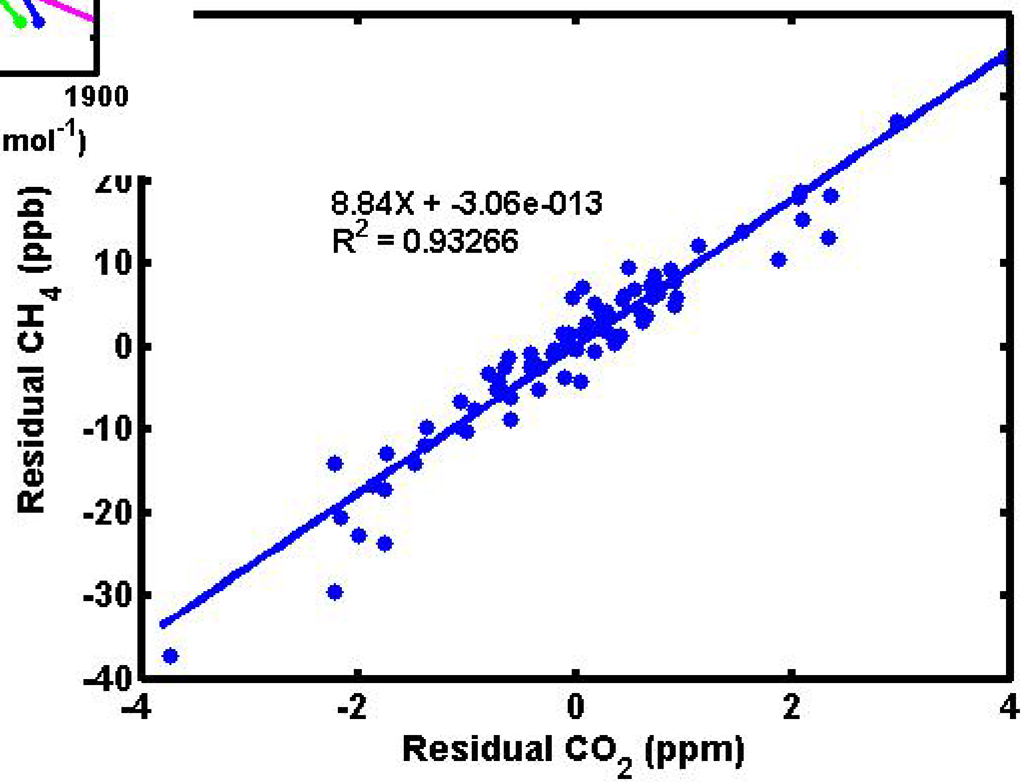
well mixed

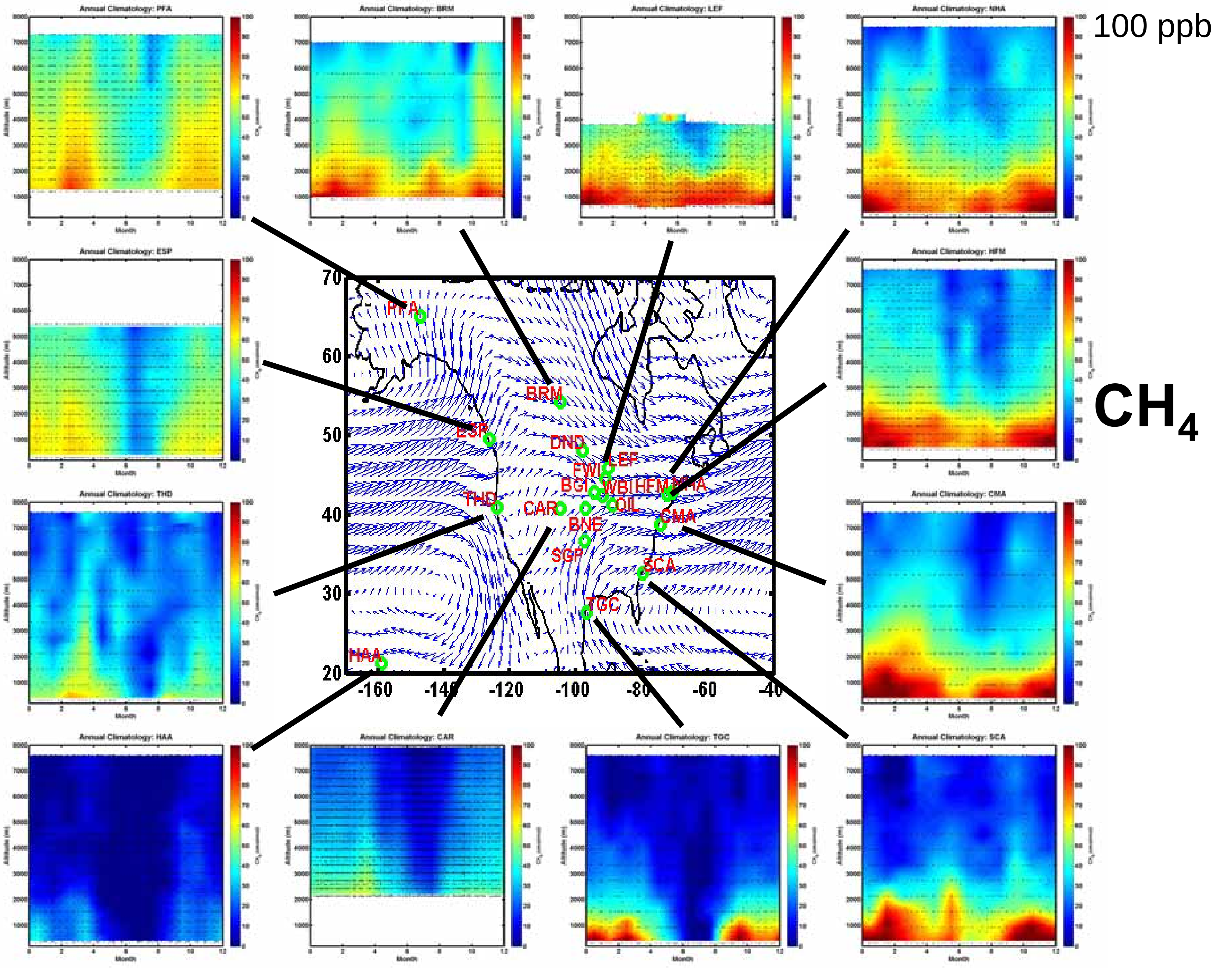
throughout column

Arctic CO_2/CH_4 Correlation



Residual of profile means show extremely good correlations in Arctic.




100 ppb
CH4
Annual Climatology: PFA
Annual Climatology: BRM
Annual Climatology: LEF
Annual Climatology: NHA
Annual Climatology: ESP
Annual Climatology: HFM
Annual Climatology: THD
Annual Climatology: CMA
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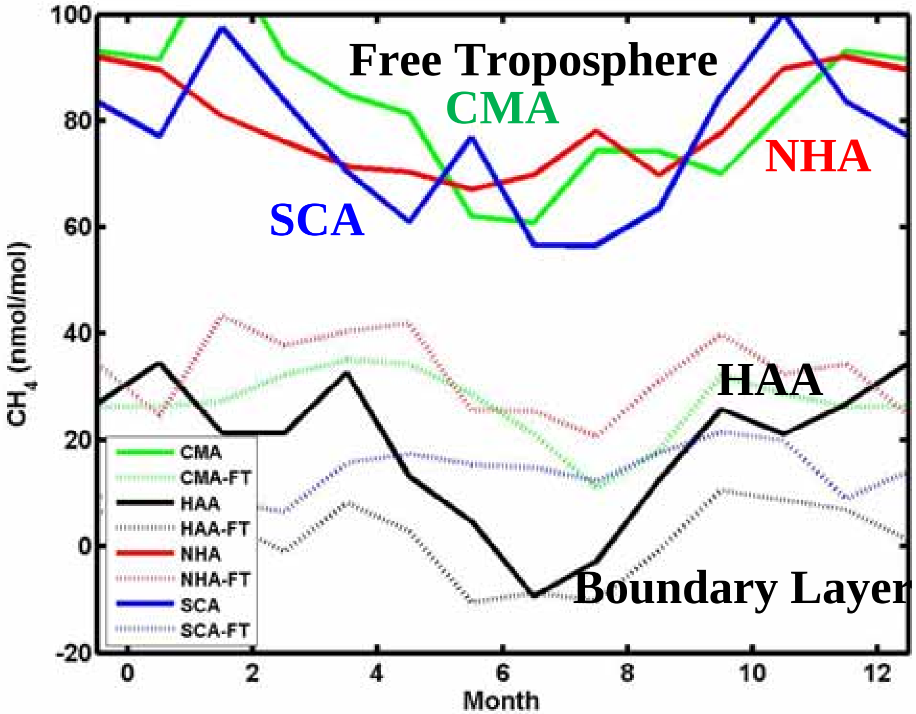
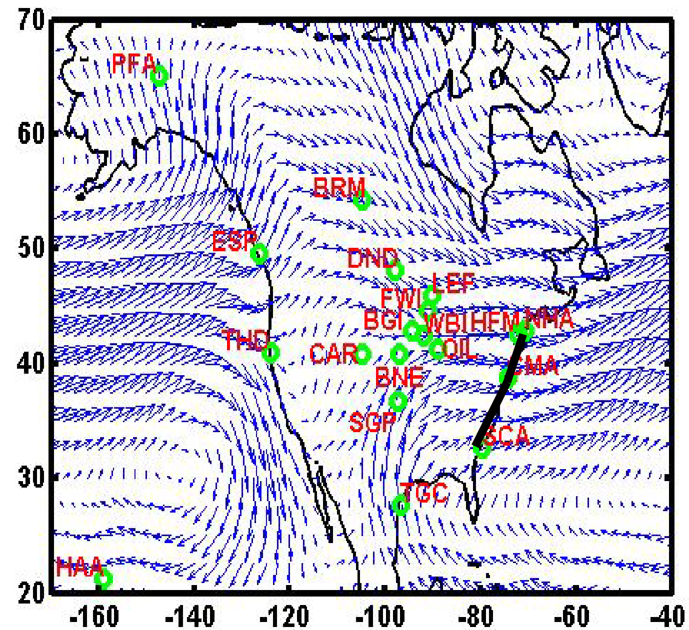
-40

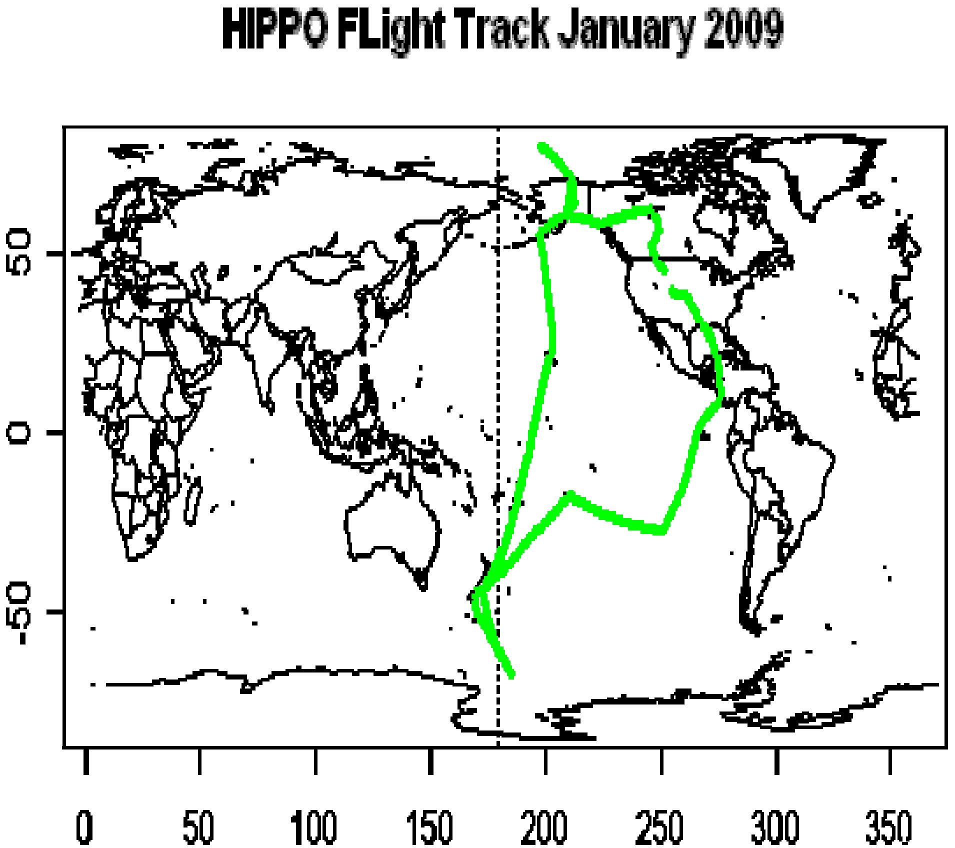
Boundary Layer Enhancement of CH_4

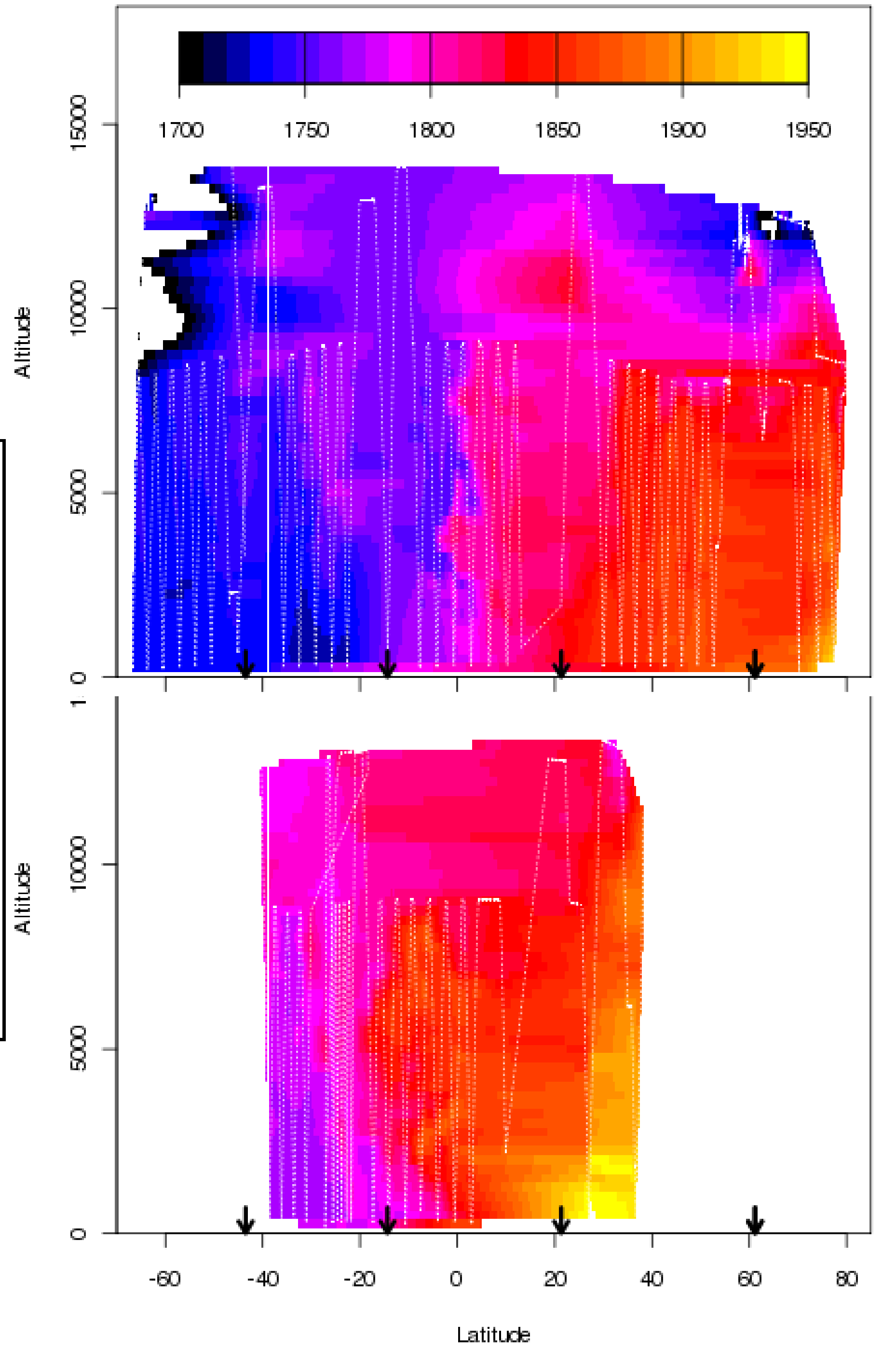


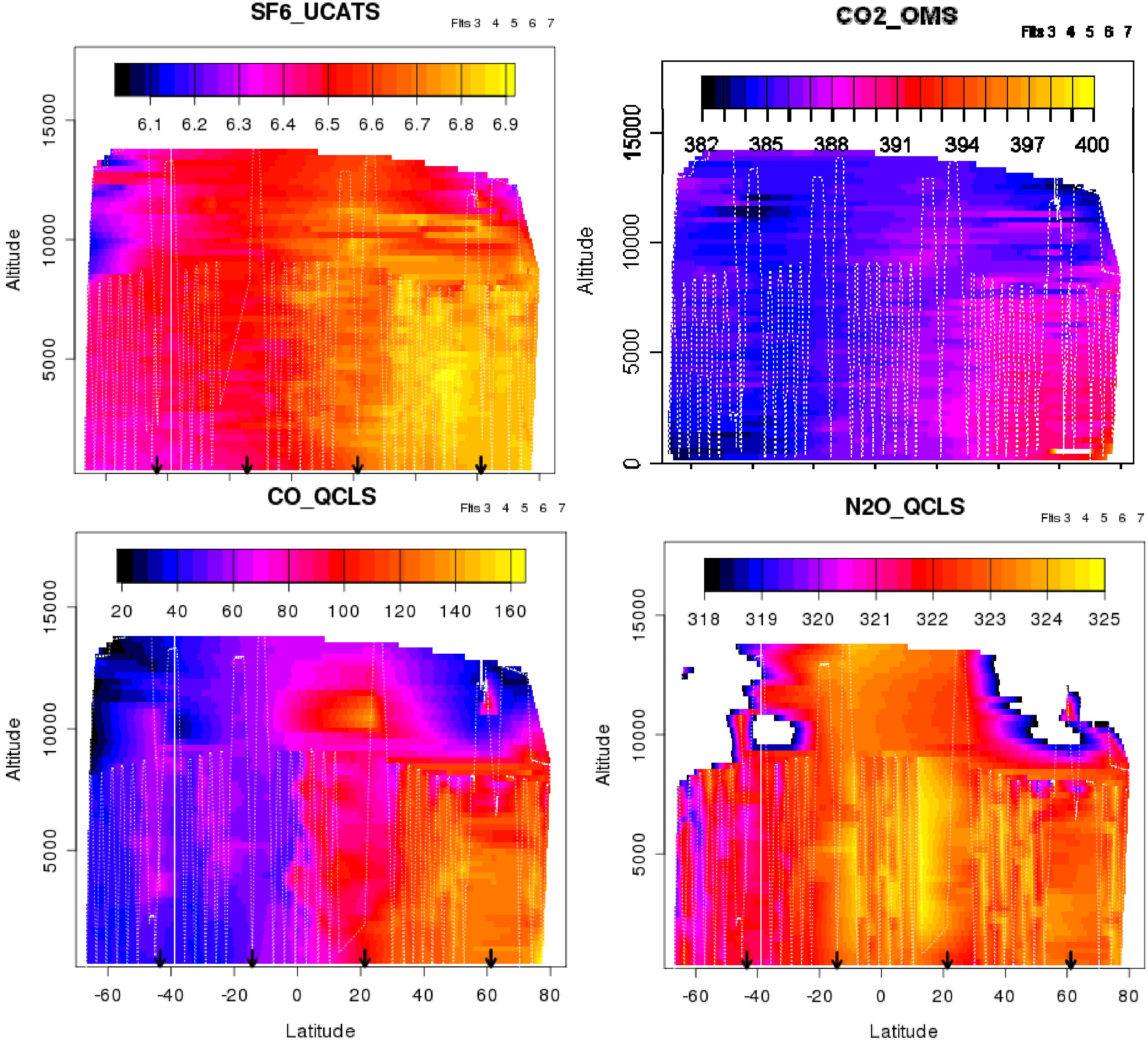
•Significant enhancement in the boundary layer suggesting a year round flux



HIPPO: HIAPER Pole-to-Pole Observations







SF6_UCATS
Flts 3 4 5 6 7
6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9
Altitude
5000
10000
15000
CO2_OMS
Flts 3 4 5 6 7
382 385 388 391 394 397 400
Altitude
0
5000
10000
15000
CO_QCLS
Flts 3 4 5 6 7
20 40 60 80 100 120 140 160
Altitude
5000
10000
15000
-60 -40 -20 0 20 40 60 80
Latitude
N2O_QCLS
Flts 3 4 5 6 7
318 319 320 321 322 323 324 325
Altitude
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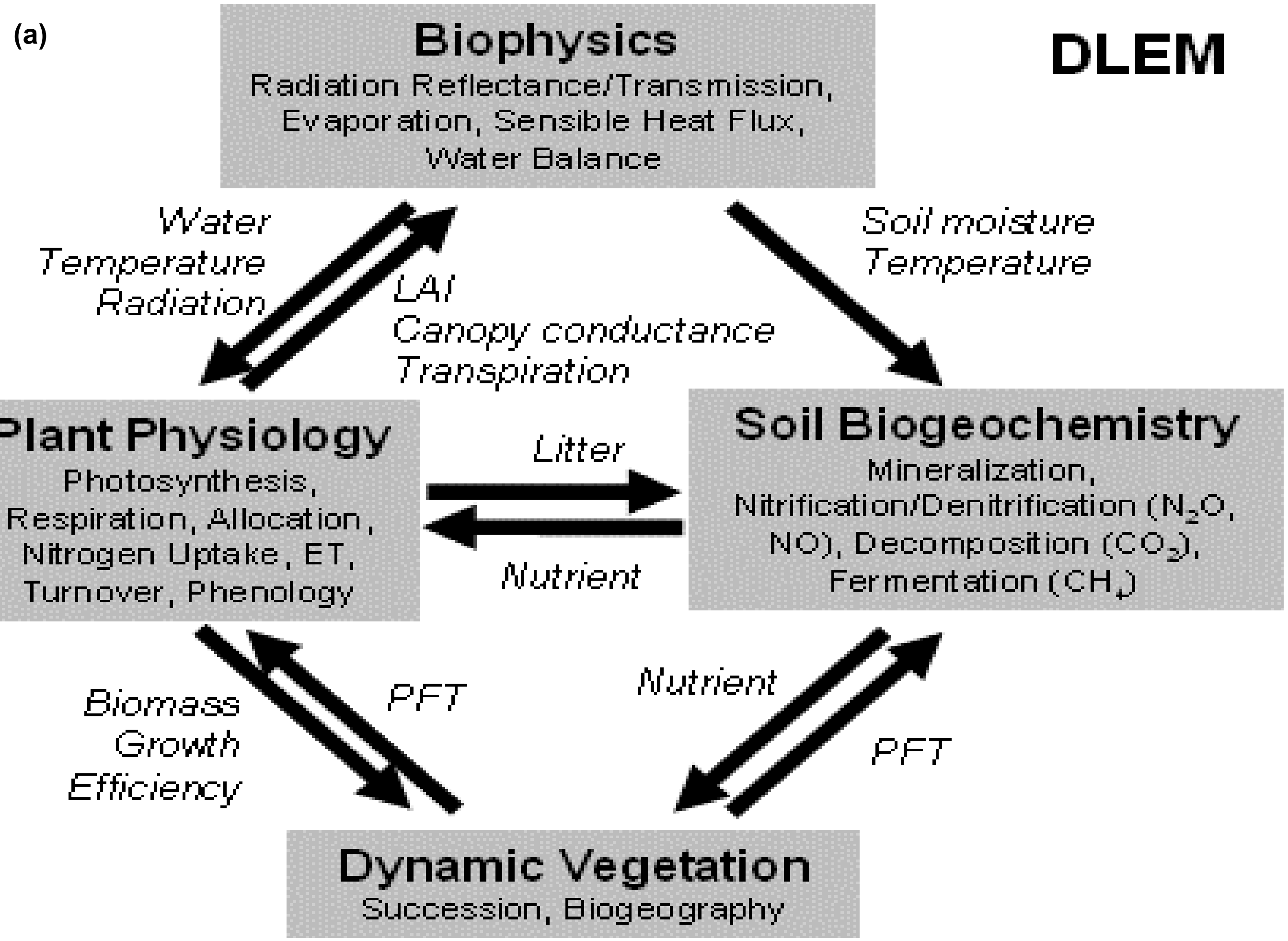
15000
-60 -40 -20 0 20 40 60 80
Latitude

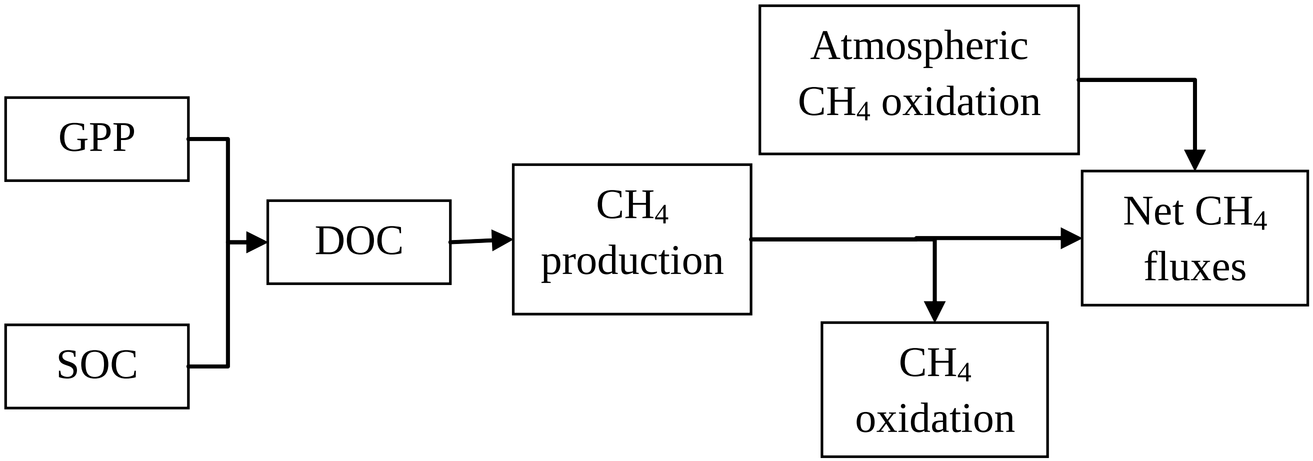
The Dynamic Land Ecosystem Model: Prior for CH_4 and N_2O fluxes

- Key components and interactions



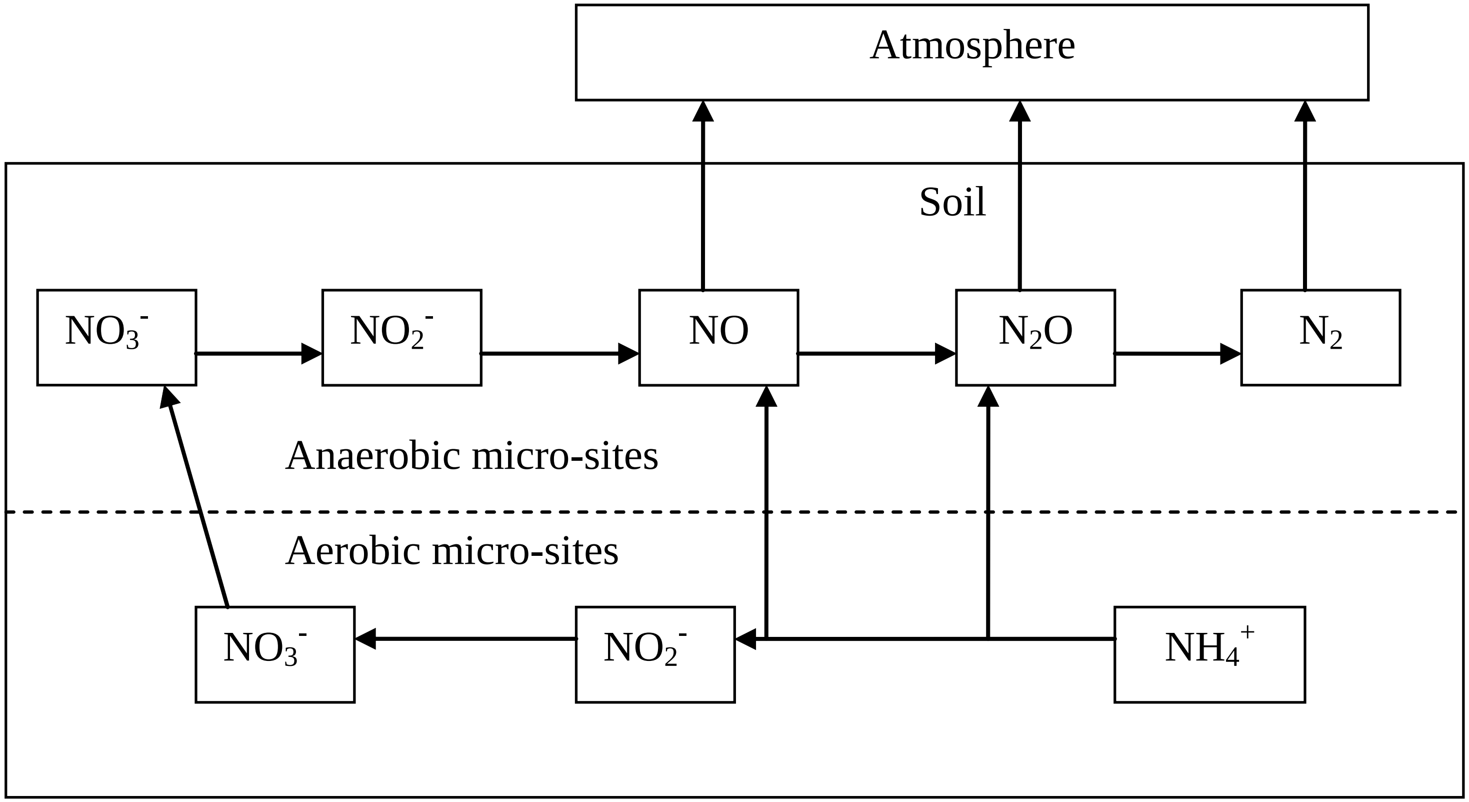
Hanqin Chen – Auburn University

Methane module of DLEM



Three methane-associated processes are incorporated in DLEM: methane production in soil, the oxidation of produced methane during transportation, atmospheric methane oxidation

Nitrous oxide module of DLEM

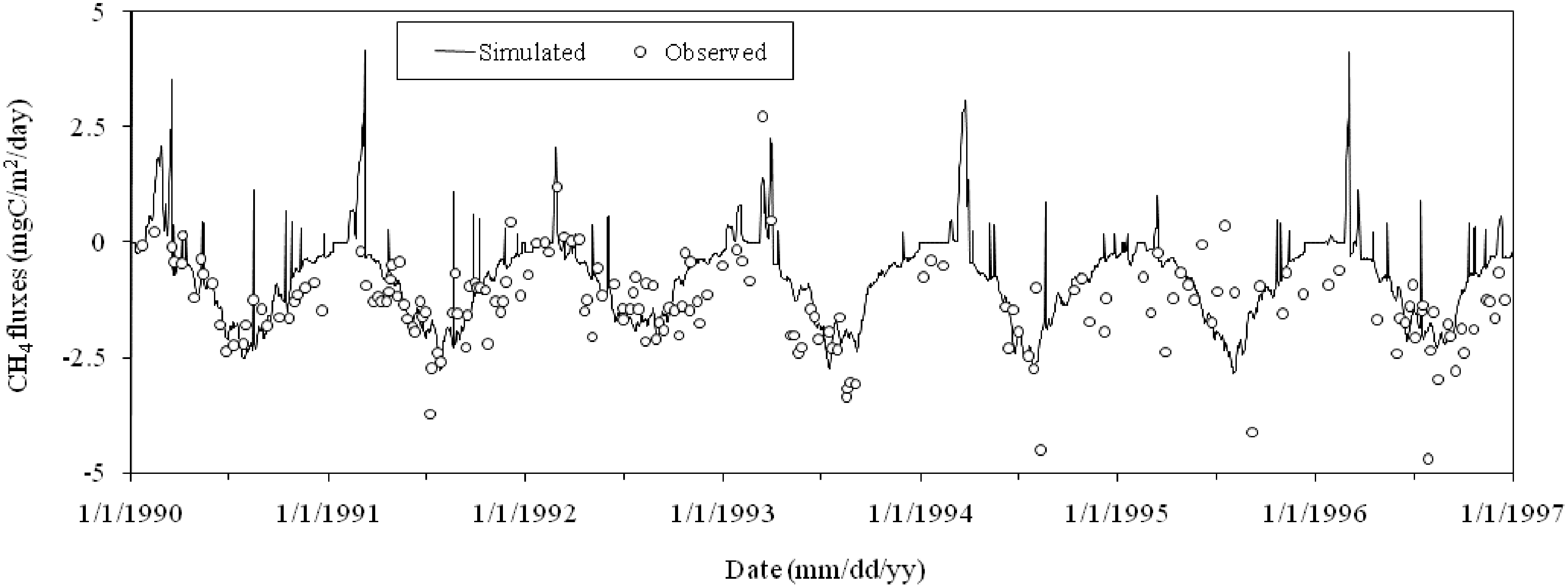


Nitrification and denitrification are determined by environmental conditions as soil moisture, temperature, pH

Model input data

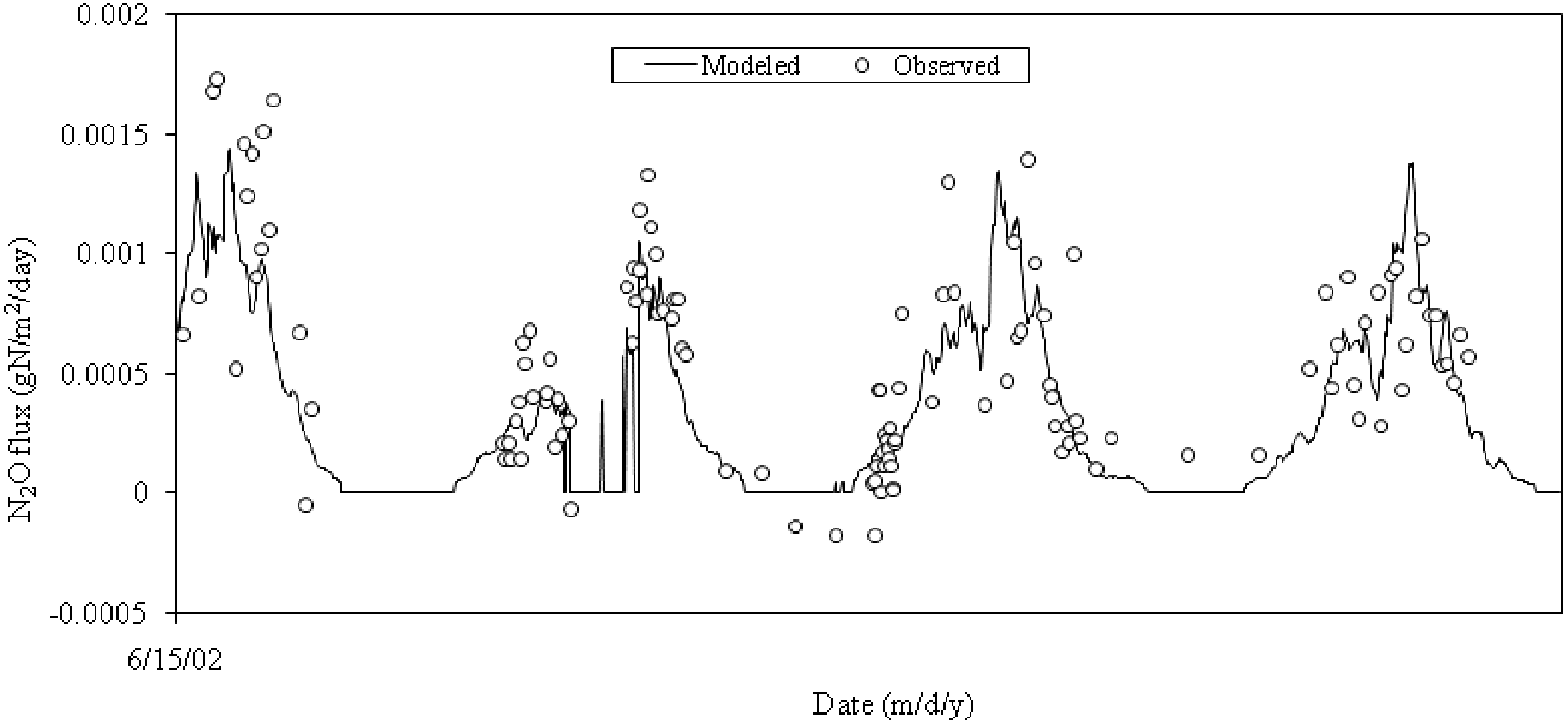
- Climate dataset (precipitation, temperature, humidity)
- Nitrogen deposition
- Ozone concentration
- Land use and land cover change
- Historical CO_2 concentration
- Fertilizer, irrigation area

Model validation for CH_4 fluxes

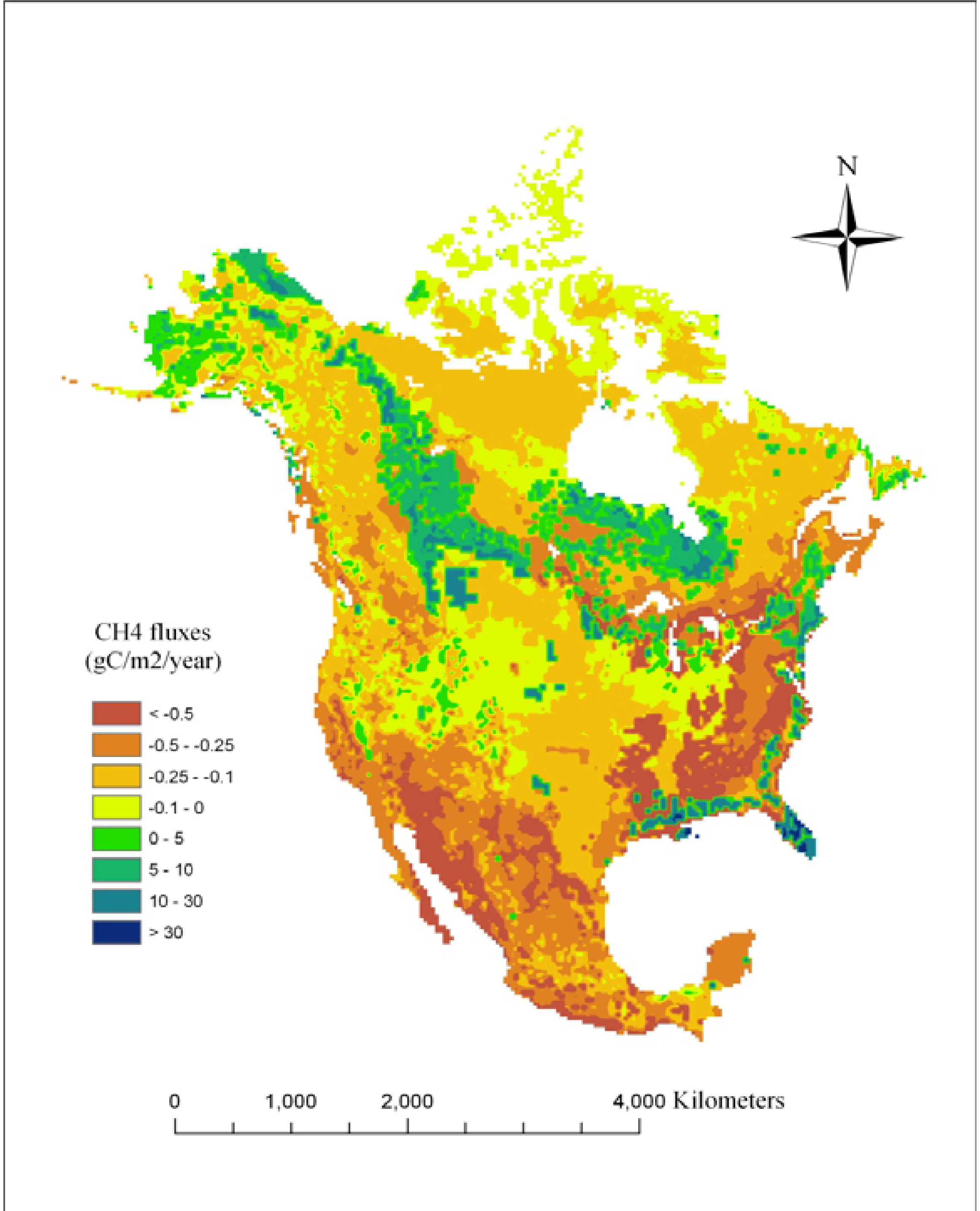


Durham forest (42N, 73W) The observed data are from BOREAS

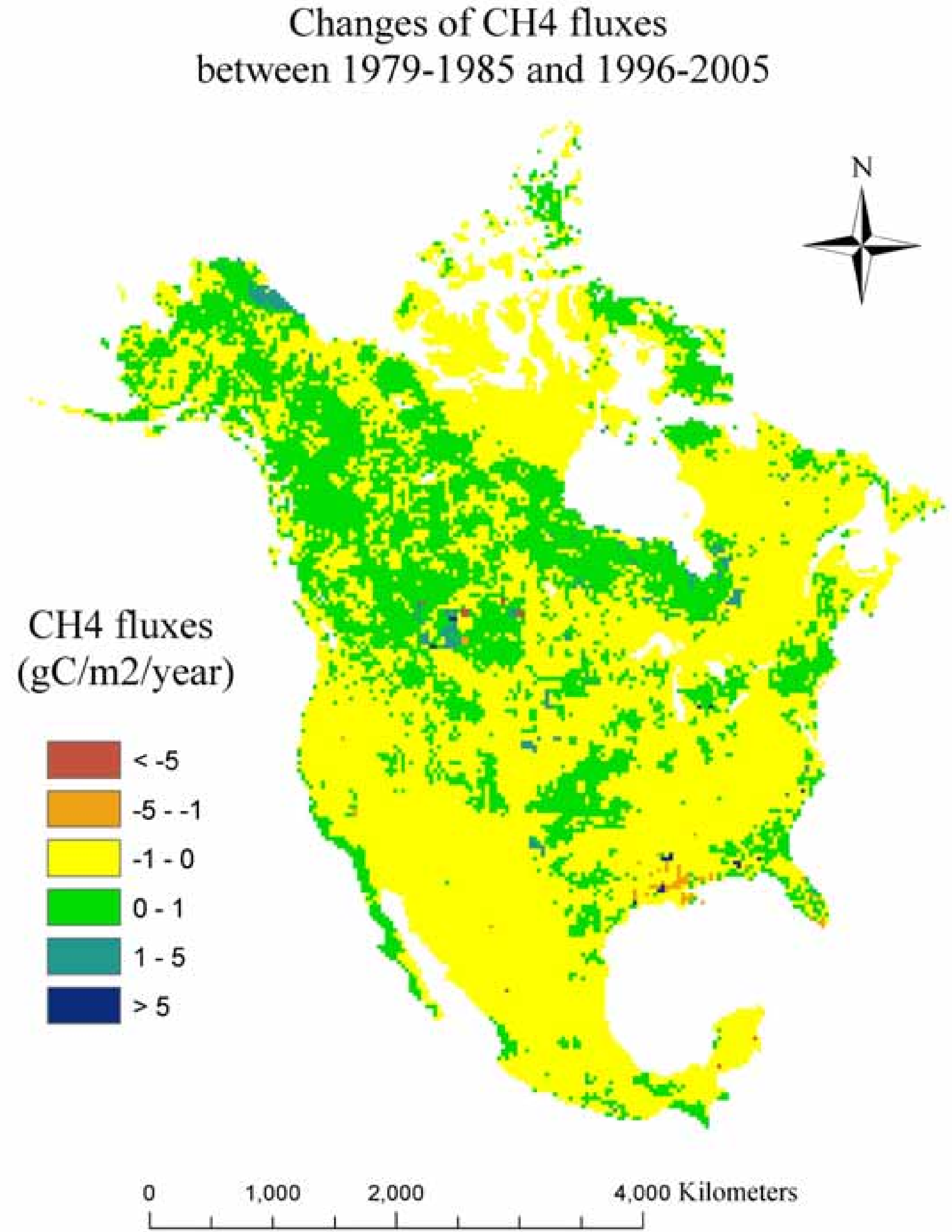
Model validation for N_2O fluxes

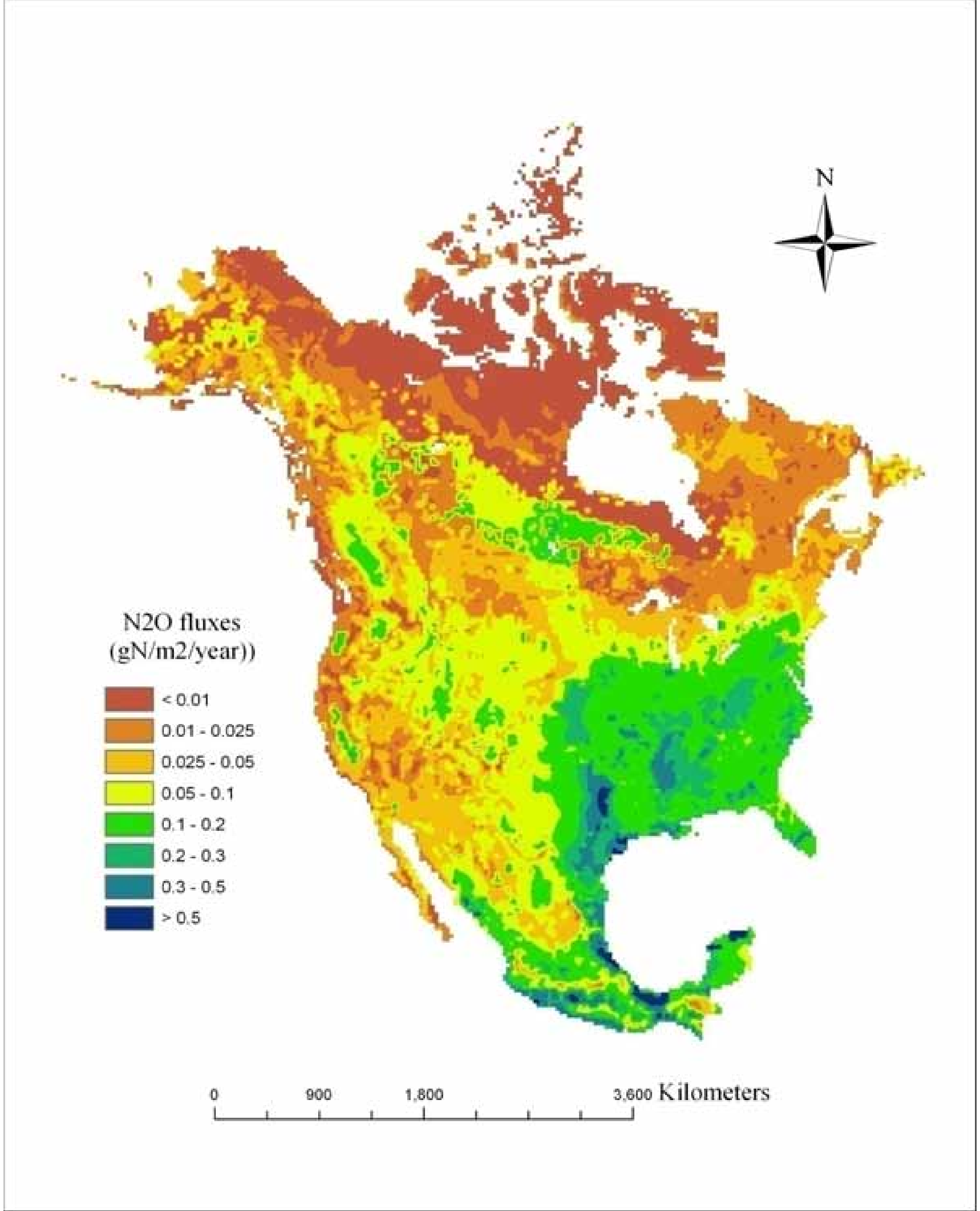


N2O from wetland (33.5E, 47.58N) Observed data are from Song et al. (2008)

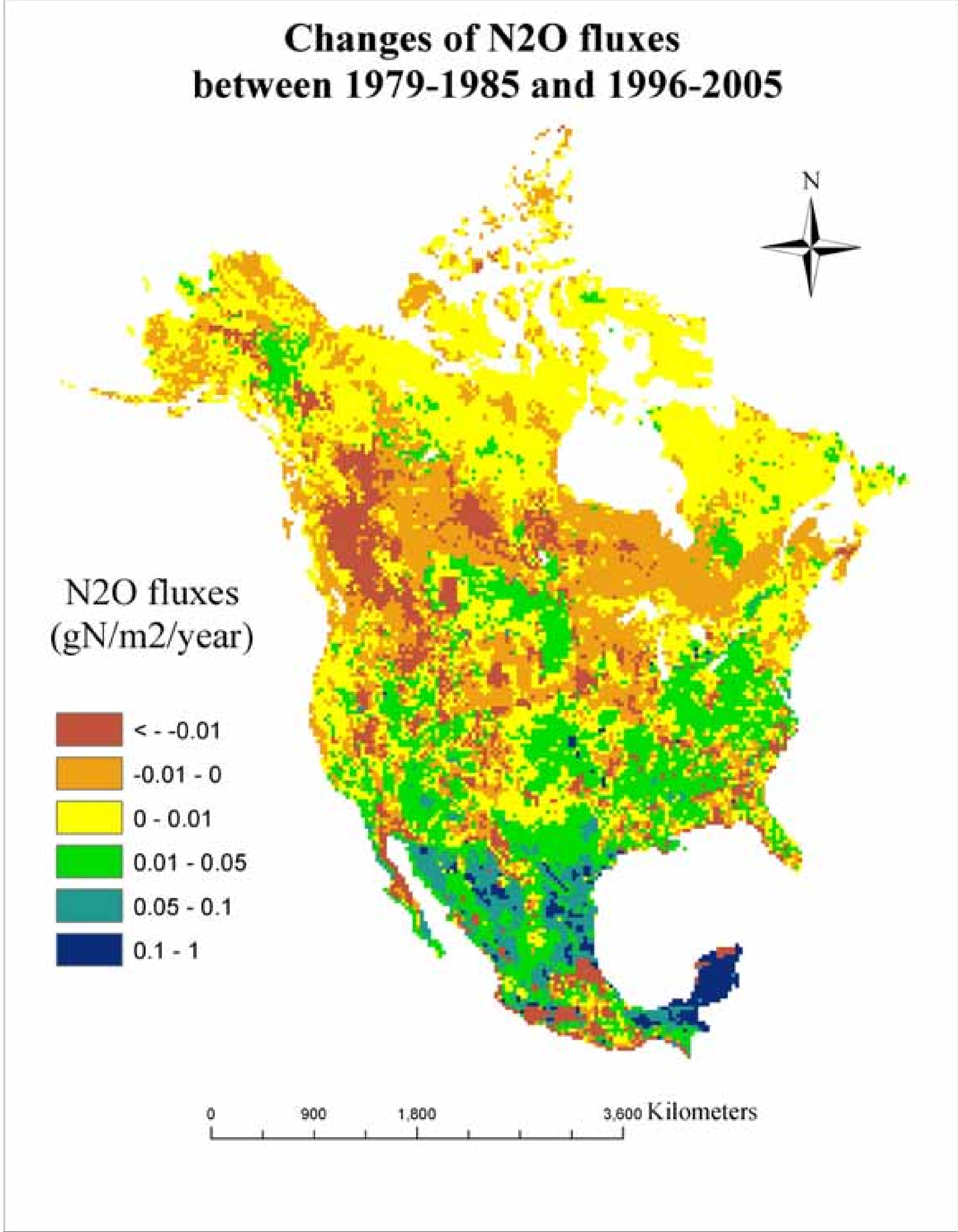


Mean annual CH_4 fluxes for 1979-1985


Changes of CH4 fluxes
between 1979-1985 and 1996-2005
N
CH4 fluxes
(gC/m2/year)
< -5
-5 - -1
-1 - 0
0 - 1
1 - 5
> 5
0
1,000
2,000
4,000 Kilometers



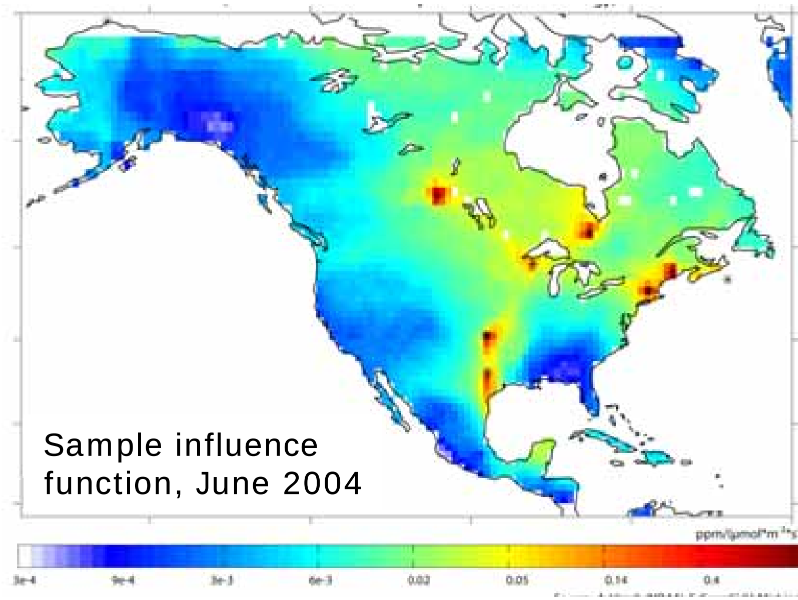
Mean annual N_2O fluxes for 1979-1985

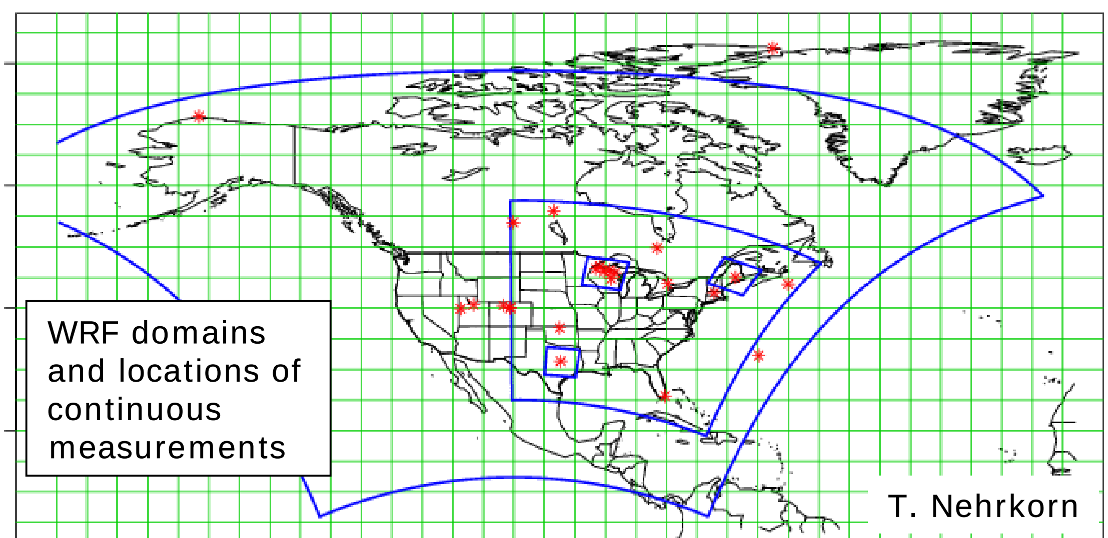

Changes of N2O fluxes
between 1979-1985 and 1996-2005
N
N2O fluxes
(gN/m2/year)
< - -0.01
-0.01 - 0
0 - 0.01
0.01 - 0.05
0.05 - 0.1
0.1 - 1
0
900
1,800
3,600 Kilometers

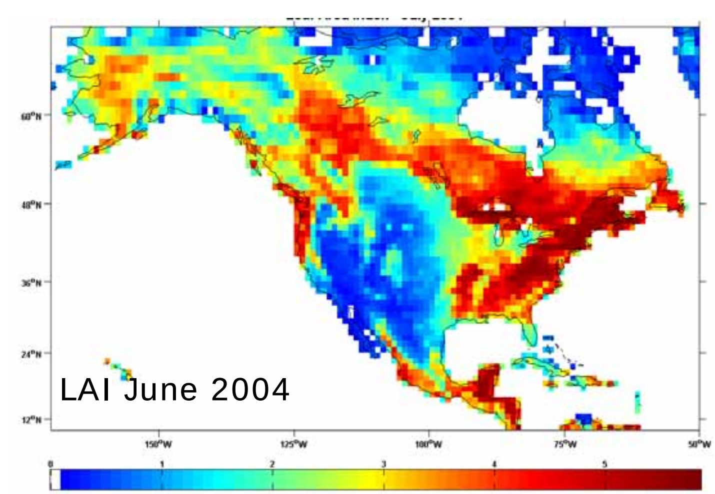
North American CO_2 Flux Estimation

Estimate North American monthly/ weekly/ daily CO_2 fluxes ($\hat{\mathbf{s}}$) at 1°x1° for 2004 to 2007 in a GIM framework using:

- CO_2 continuous







NACP Synthesis Project:
Spatial and Temporal Distributions of Sources for non-CO_2 Greenhouse Gases (CH_4, CO, N_2O, SF_6, PFCs,…) in North America

Deliverables of the Synthesis activity

1. A comprehensive data base in uniform, accessible format.

2. A set of bottom-up source fields for North America, with best possible spatial and temporal resolution, disaggregated by source type—the prior for a Bayesian Inverse Model (or auxiliary data, for Geostatistical Inverse Modeling). *DLEM*

3. Model—data fusion products giving the "best possible" emissions fields, plus aggregated budgets and inventories for target gases in the NACP domain.

Agenda

Wed 20081022

AM

9:00 am Steve Wofsy, greet with intro

9:15 am Arlyn Andrews (NOAA): "*Comprehensive overview of the NOAA ESRL network measurements of greenhouse gases.*"

9:45 am Colm Sweeney: "*Observations of non-CO_2 gases from the NOAA/ESRL aircraft network: what you learn from 2000 vertical profiles*"

10:15 am Paul Wennberg "*New results for CO and CH_4 from TCCON FTS data*"

10:45 am coffee break

11:00 am Patrick Crill: "*Measurements of CH_4 fluxes from natural, agricultural and built Environments*"

11:30 am Doug Worthy: "*Environment Canada Network data: What we have learned about CH_4 emissions in Canada*"

12:00 Lunch (at cafeteria)

PM

1:00 pm Elaine Matthews: "*Distributions of wetlands: from satellites to nav charts*"

2:00 Steve Wofsy: "*Data Archive for NACP sythesis: Summary of 'Best Practices' data format, metadata, etc…*"

Breakout sessions

1) Data Set Compendium: content, format

2) Preliminary Discussion of Synthesis Projects.

Agenda (continued)

Thursday 20081023

AM

9:00 am Breakout reports

9:30 am Matt Rigby: "*N_2O, CH_4, and halocarbons from AGAGE*"

10:00 am Anna Michalak: "*Determining regional emissions patterns: Strengths and Weaknesses of Bayesian vs. geostatistical methods*."

coffee break

11:00 am Hanqin Tian: "*Comprehensive bottom-up fluxes for natural and human-influenced systems from the DLEM Ecosystem model for N_2O & CH_4*"

11:30 am Lori Bruhwiler: "*Preliminary results from the Carbontracker® -- Methane Ensemble Kalman filter*"

12:00 Lunch

PM

1:00 pm Adam Hirsch: "*Global and regional N_2O inversions*"

1:30 pm Steve Montzka: "*COS + halocarbons from NOAA HATS & CCCG: critical elements among next-tier species*"

2:00 pm Eric Kort: "*CH_4 and N_2O sources from aircraft data using high-resolution LPDMs*"

2:30 pm Marc Fischer "*California Central Valley and ARM-CARTT data*"

Breakout session

Formulation of synthesis activities and products