Project Review

A Coupled Measurement-Modeling Approach to Improve Biogenic Emission Estimates: Application to Future Air Quality Assessments

Huiting Mao, Ming Chen, Barkley Sive, Robert Talbot, Ruth Varner and Robert Griffin
University of New Hampshire

RTP, NC
February 21, 2007

UNIVERSITY of NEW HAMPSHIRE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

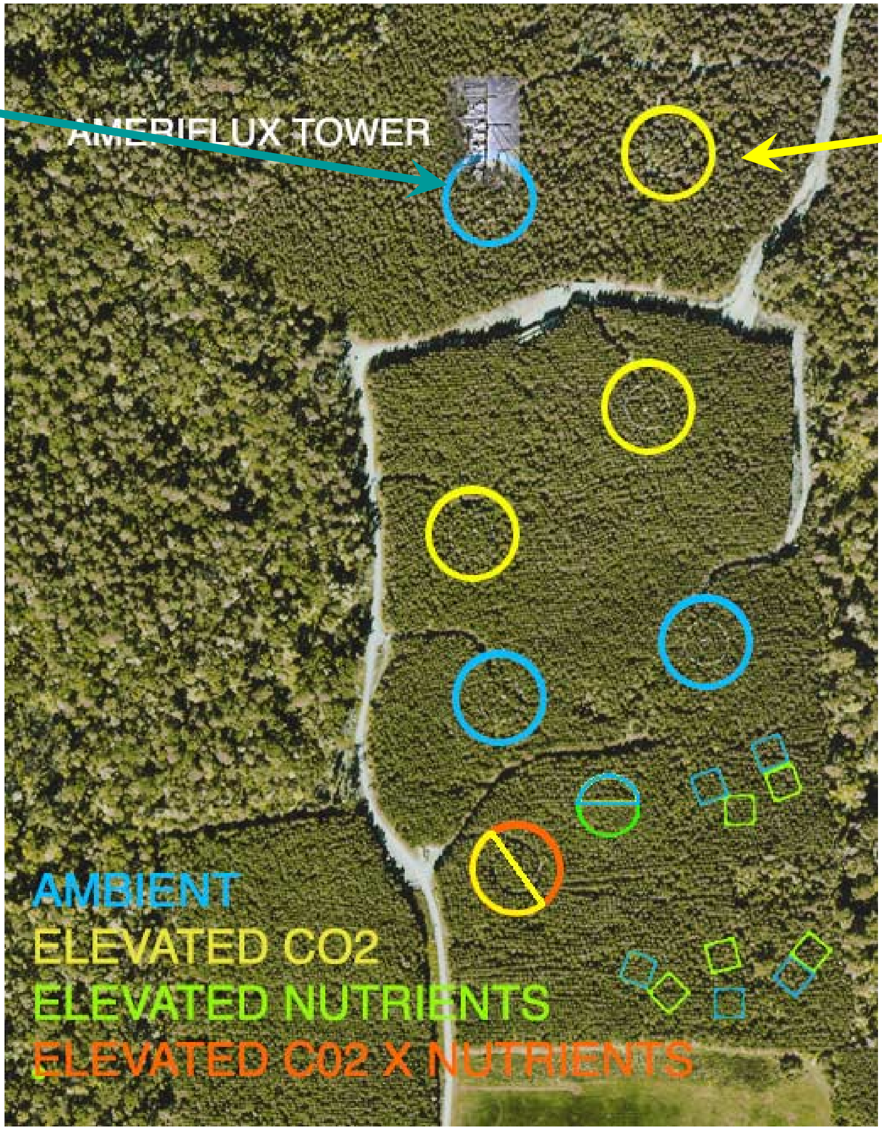
AIRMAP

Objectives

- To predict changes in climate that influence biogenic emissions and air quality.
- To quantify the impact of climate change on plant ecosystem composition.
- To estimate the impact of a changing plant ecosystem on biogenic emissions.
- To estimate the impact of changes in regional climate and plant ecosystem on aerosol loading, O_3, NO_x, hydrocarbons, and the oxidative capacity of the atmosphere.

TRACK I: CO_2 ENRICHMENT RESEARCH – Measurements at the Duke Forest FACTS-I site

Ring 1
Ambient CO_2



Ring 2
Elevated CO_2
(Ambient+200 ppmv)

Measurements at Duke Forest

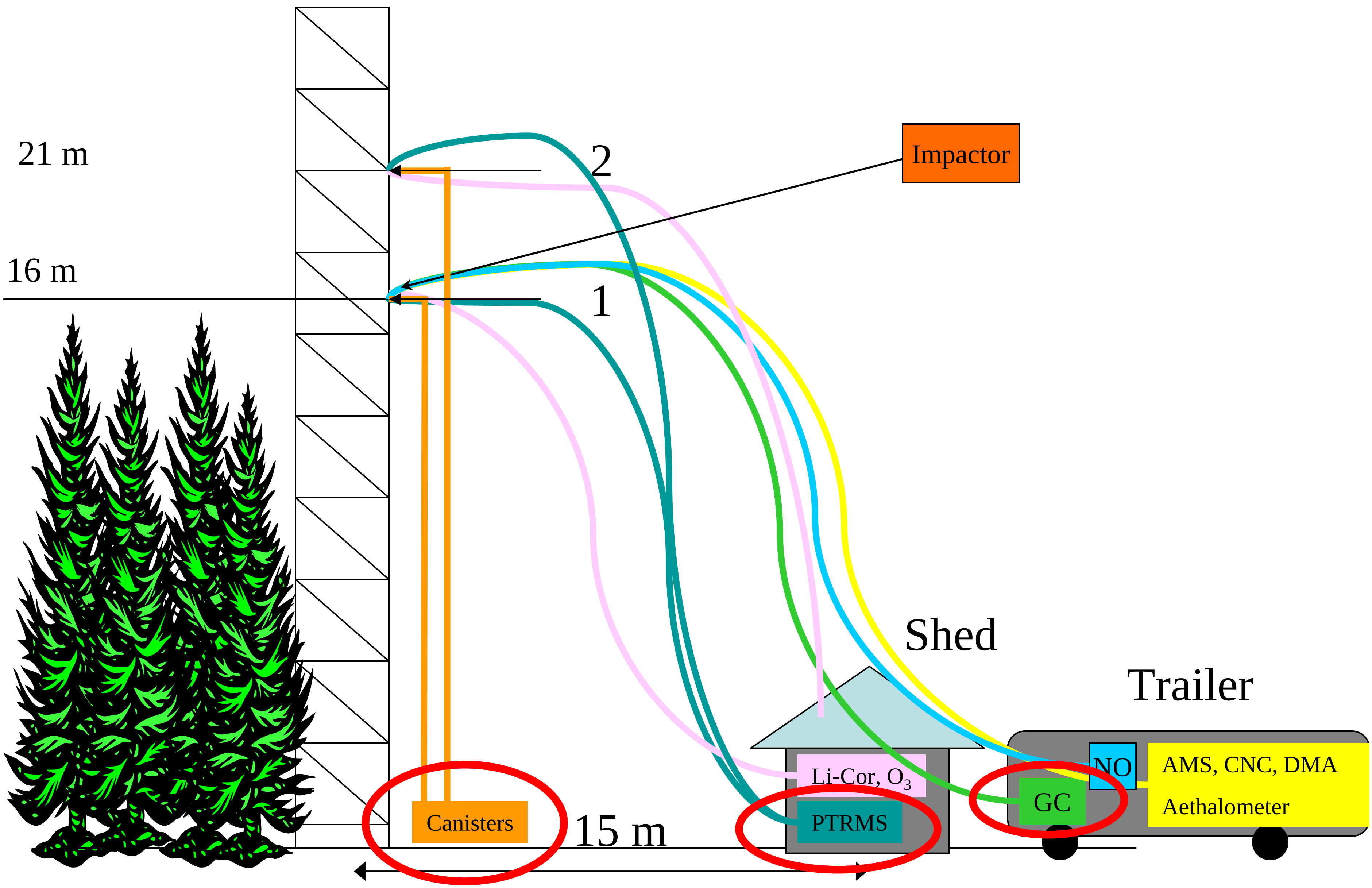
NMHCs
Halocarbons
Alkyl Nitrates
OVOCs
O_3
NO
CO_2
H_2O

SOA & POA – number density, size distribution and composition (AMS, CN, filters)
Black Carbon
Met Data

3 Field Campaigns

1. Canopy: September 2004
2. Vegetation and Soil: June 2005
3. Soil: September 2005

Trace Gas Measurements: September 2004



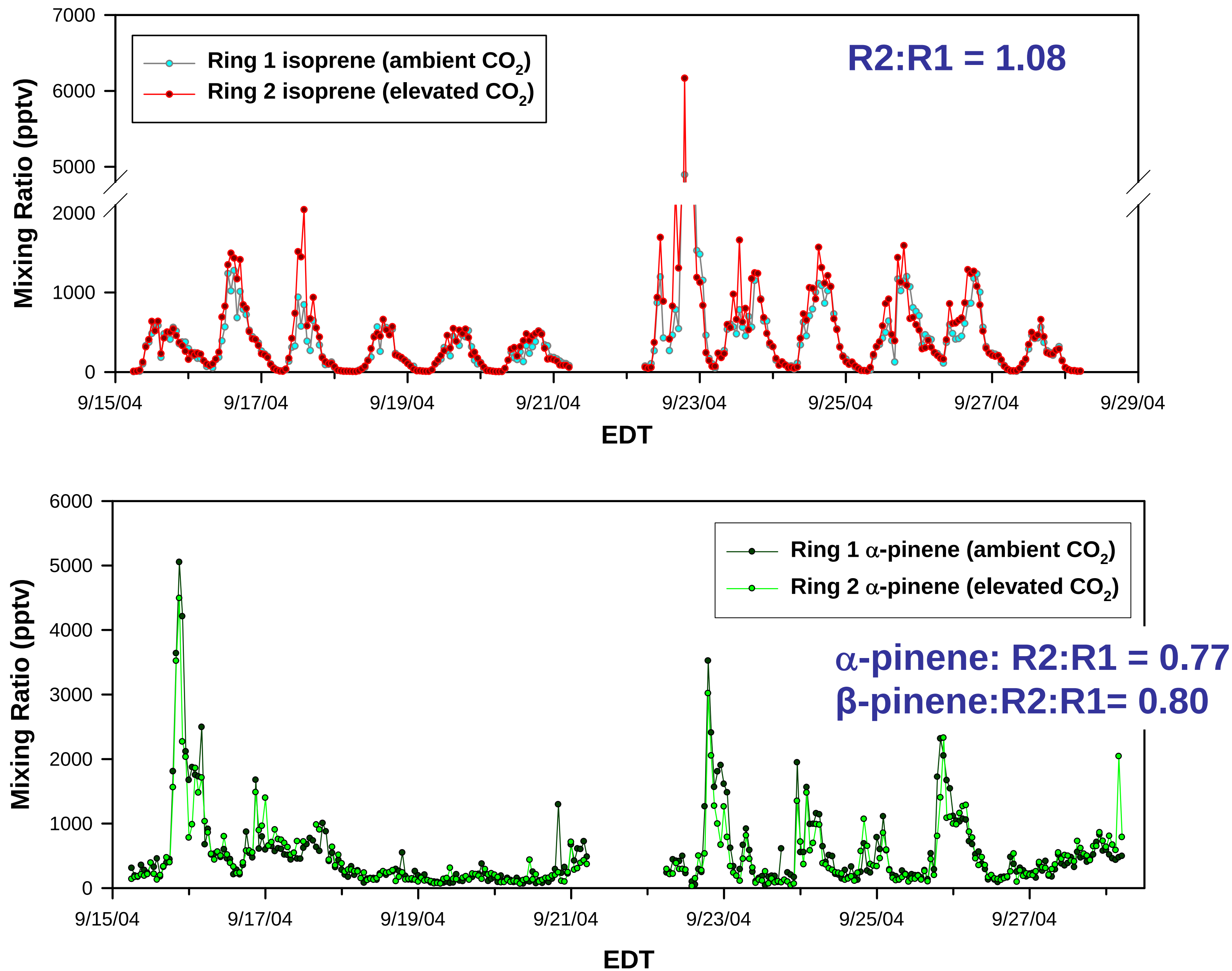
Vegetation Flux Measurements: June 2005

Loblolly Pine
(Pinus taeda)

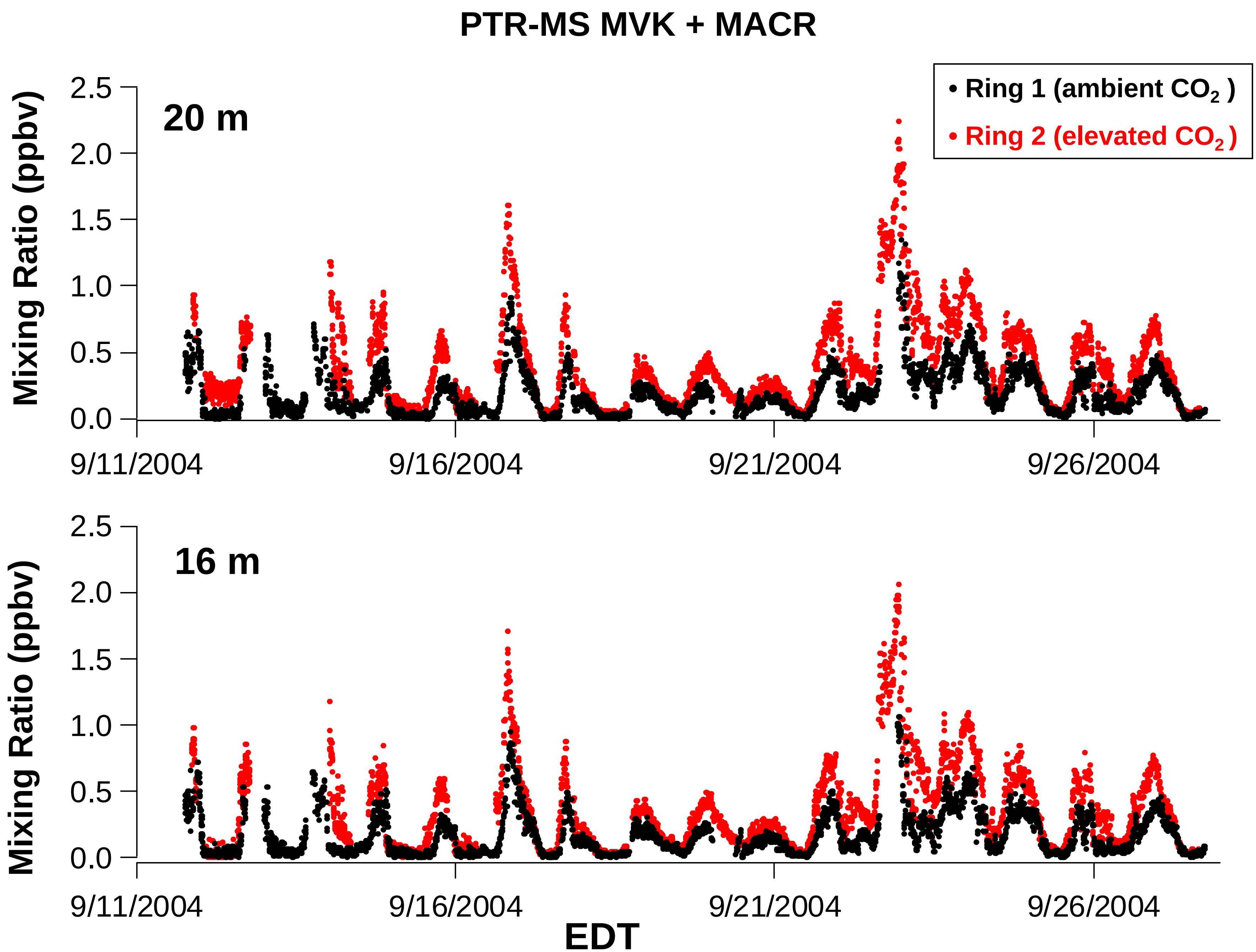
Branch enclosure measurements made every 2 hours over 2 day period for each species.

Sweet Gum
(*Liquidambar styraciflua*)

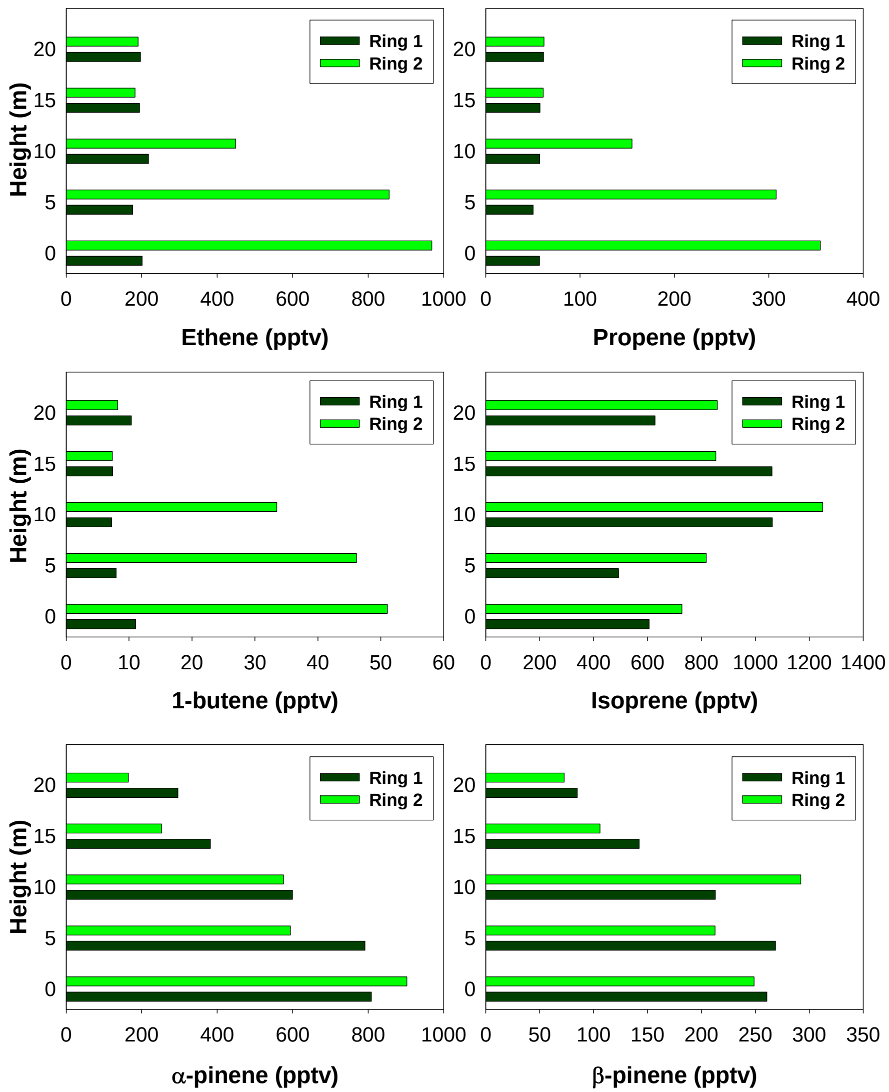
Soil Fluxes: June and September 2005



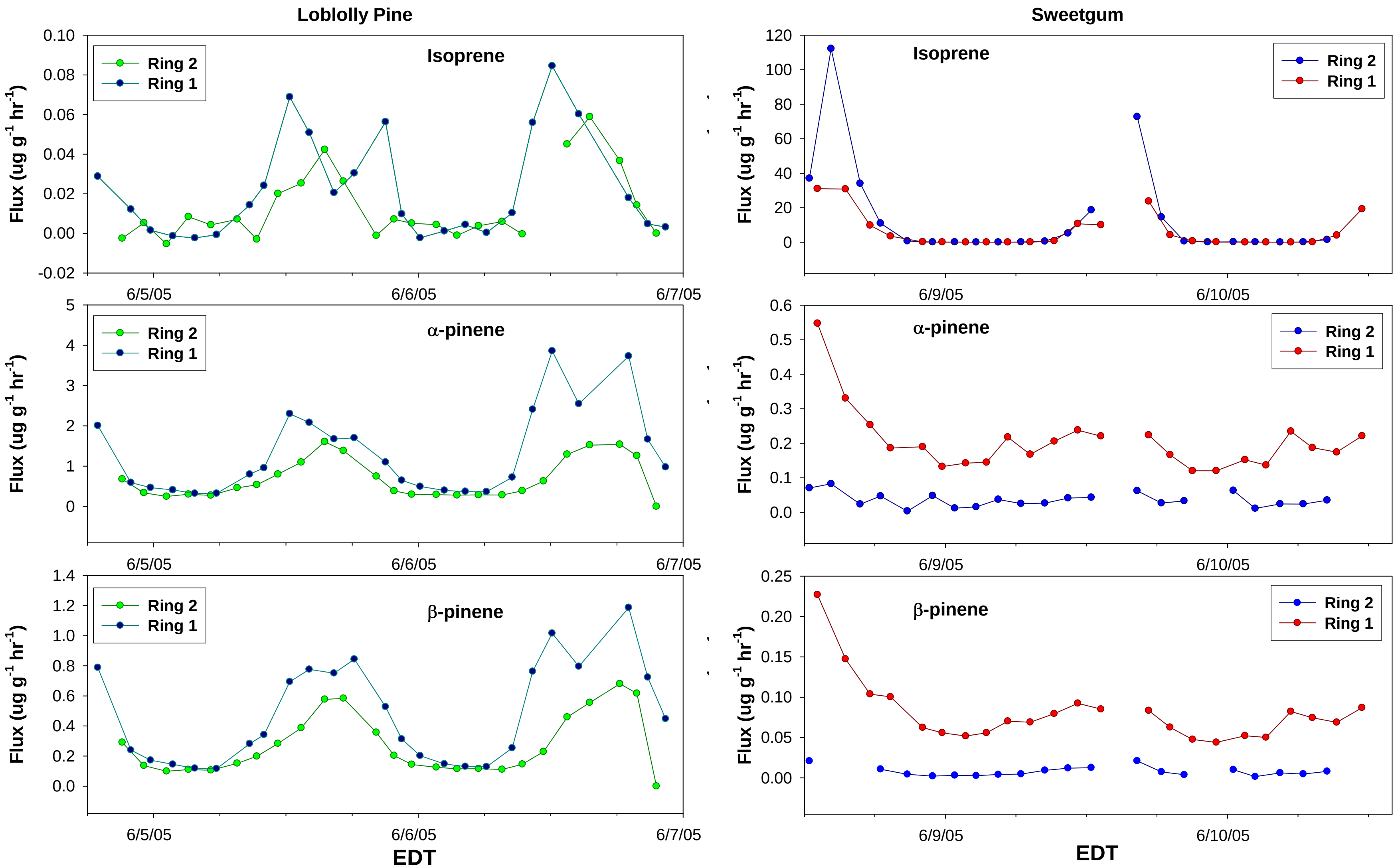
Ring 1 isoprene (ambient CO_2)
Ring 2 isoprene (elevated CO_2)
R2:R1 = 1.08
Mixing Ratio (pptv)
7000
6000
5000
2000
1000
0
9/15/04
9/17/04
9/19/04
9/21/04
9/23/04
9/25/04
9/27/04
9/29/04
EDT
Ring 1 α-pinene (ambient CO_2)
Ring 2 α-pinene (elevated CO_2)
α-pinene: R2:R1 = 0.77
β-pinene:R2:R1= 0.80
Mixing Ratio (pptv)
6000
5000
4000
3000
2000
1000
0
9/15/04
9/17/04
9/19/04
9/21/04
9/23/04
9/25/04
9/27/04
EDT



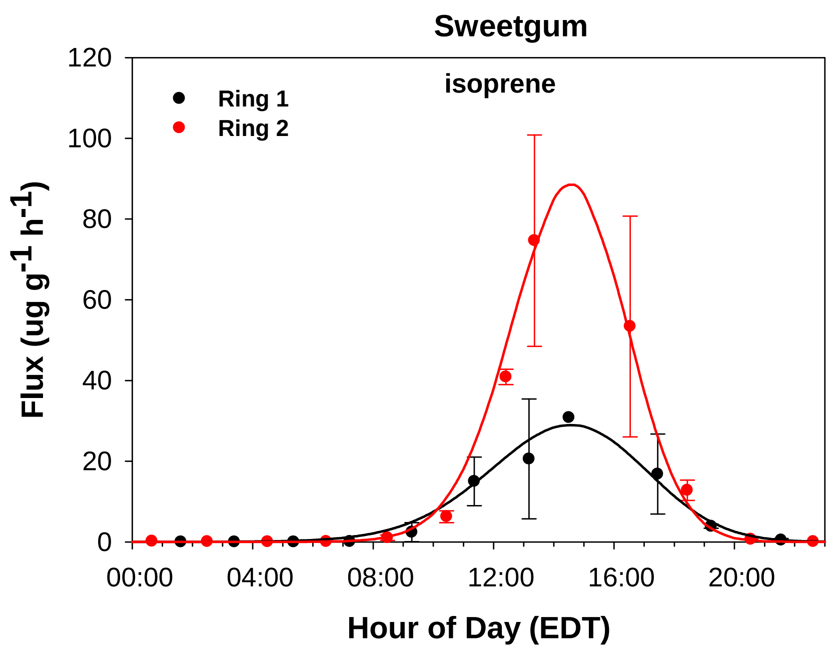
PTR-MS MVK + MACR
20 m
16 m
Ring 1 (ambient CO_2)
Ring 2 (elevated CO_2)
Mixing Ratio (ppbv)
2.5
2.0
1.5
1.0
0.5
0.0
9/11/2004
9/16/2004
9/21/2004
9/26/2004
EDT



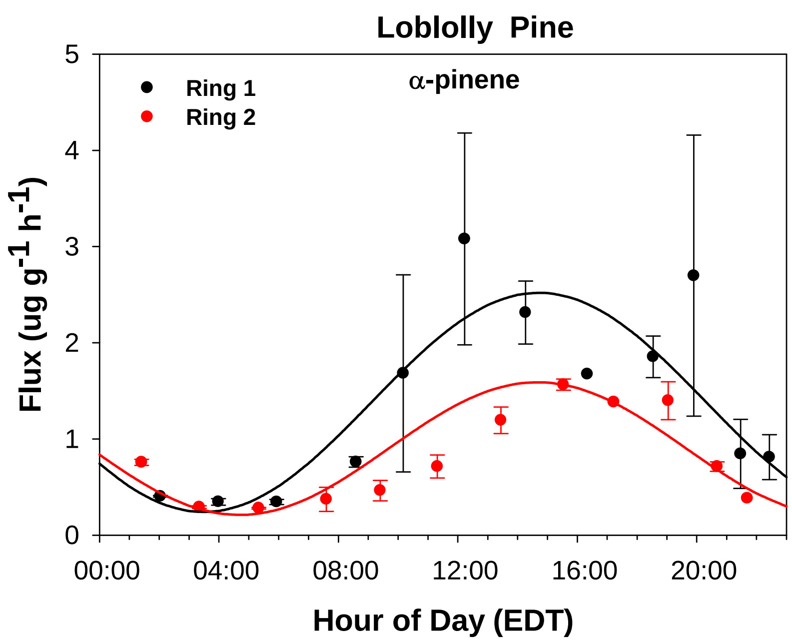
- Below-canopy profiles of a suite of VOCs measured.
- Source of reactive alkenes in the lower forest canopy/soil in the elevated CO_2 ring.
- Some uptake of isoprene near the surface.
- Possible soil emissions of terpenes.



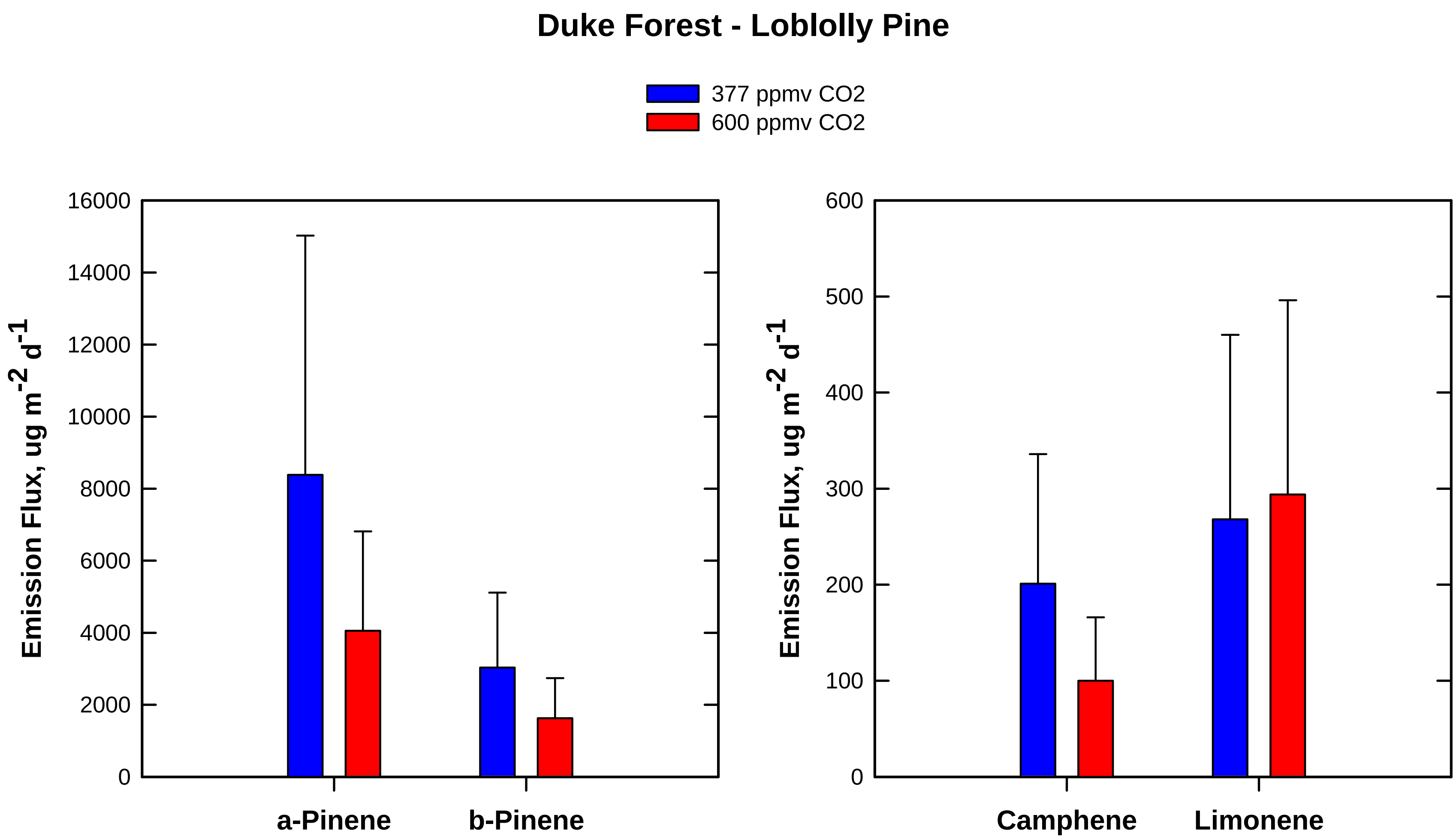
Loblolly Pine
Sweetgum
Isoprene
α-pinene
β-pinene
Ring 2
Ring 1
Flux (ug g-1 hr-1)
6/5/05
6/6/05
6/7/05
6/9/05
6/10/05
EDT

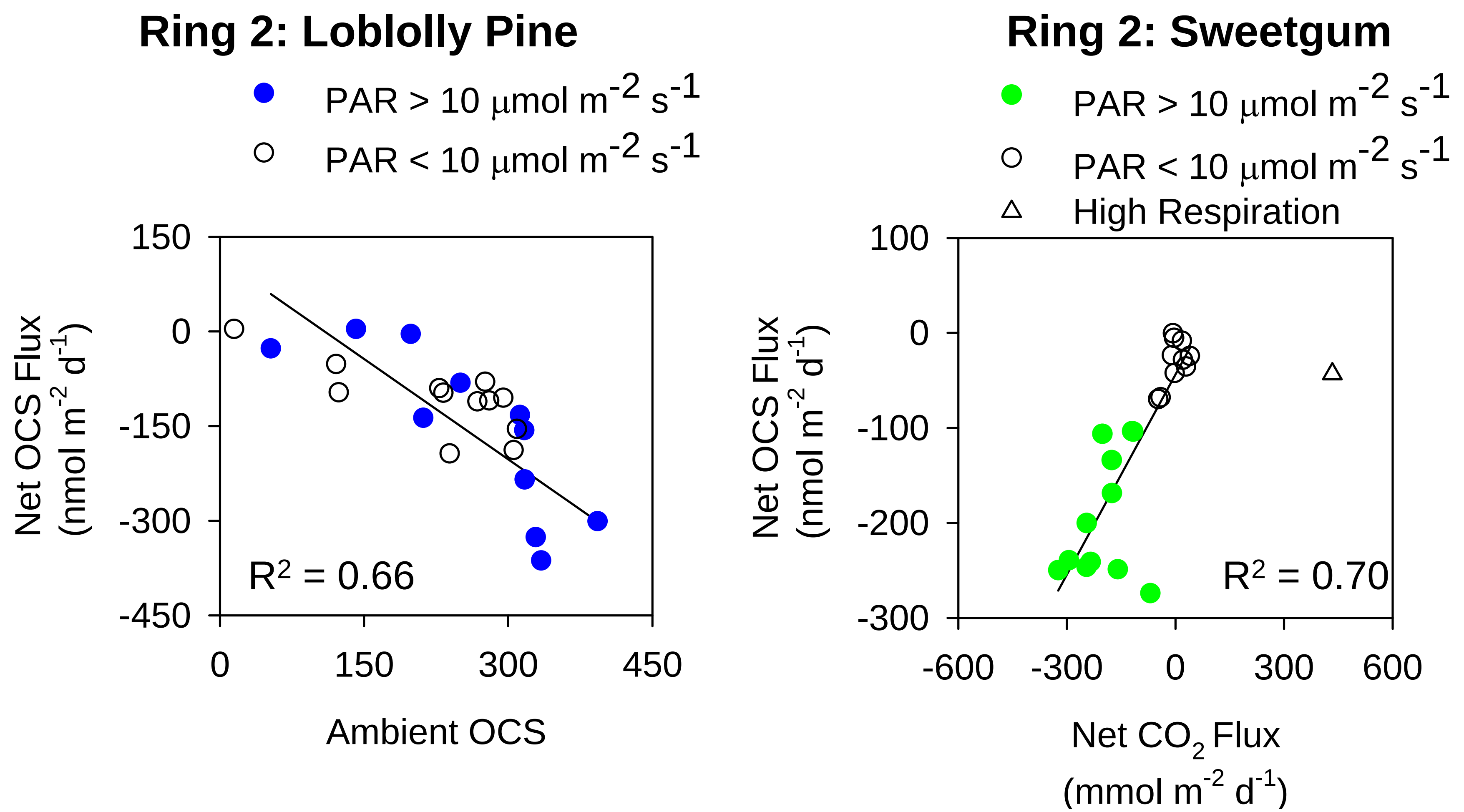


Sweetgum
isoprene
Ring 1
Ring 2
Flux (ug g-1 h-1)
120
100
80
60
40
20
0
00:00
04:00
08:00
12:00
16:00
20:00
Hour of Day (EDT)



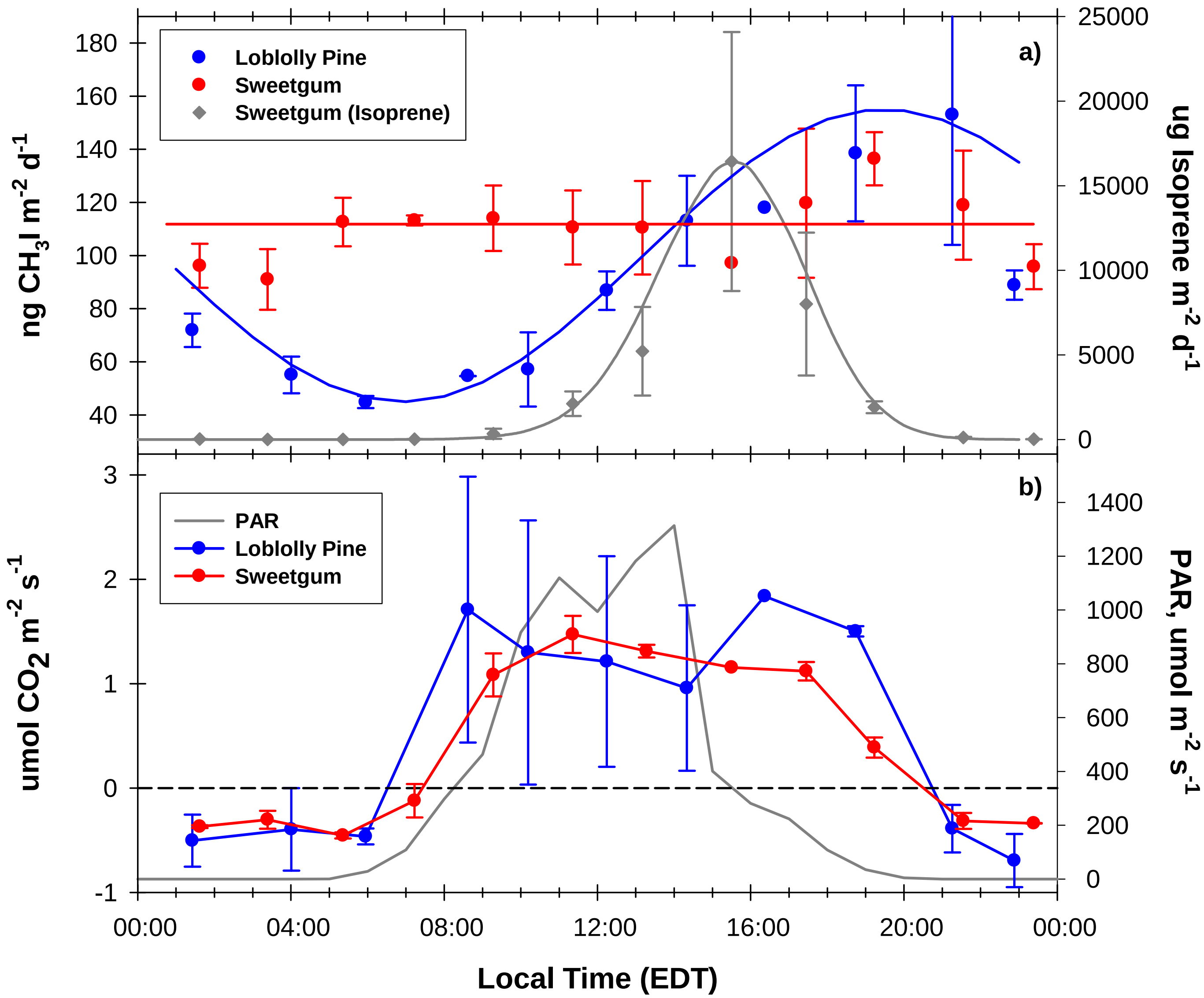
Loblolly Pine
α-pinene
Ring 1
Ring 2
Flux (ug g-1 h-1)
5
4
3
2
1
0
00:00
04:00
08:00
12:00
16:00
20:00
Hour of Day (EDT)


Duke Forest - Loblolly Pine
377 ppmv CO2
600 ppmv CO2
Emission Flux, ug m-2 d-1
16000
14000
12000
10000
8000
6000
4000
2000
0
a-Pinene
b-Pinene
Emission Flux, ug m-2 d-1
600
500
400
300
200
100
0
Camphene
Limonene



OCS uptake is tree species-dependent: ambient OCS level for Loblolly pine and net CO_2 flux for sweetgum.

White et al. [2007]



Emissions of CH_3I from the two tree species were comparable, but with a distinct diurnal cycle from Loblolly Pine and none from Sweetgum (emission not stomatally driven). *Sive et al.* [2007]

Key Points from Vegetation and Soil Flux Measurements

Loblolly Pine

Emission fluxes of α-pinene, β-pinene, & camphene ~50% lower under enhanced CO_2 conditions ($p = 0.01$).

OCS uptake is tree species dependent: it increases with the ambient OCS level.

Sweetgum

β-pinene emission flux ~200% lower under enhanced CO_2 conditions ($p = 0.01$).

OCS uptake is tree species dependent: it decreases with enhanced CO_2.

*Limonene emission fluxes were not significantly different between the two CO_2 environments for either tree species.

*Terrestrial vegetation and soils make a significant contribution to CH_3I regional and global budgets.

*CO_2 enrichment does not have a significant effect on CH_3Cl or CH_3Br exchange.

Soil

Wide spatial and temporal variability in soil fluxes.

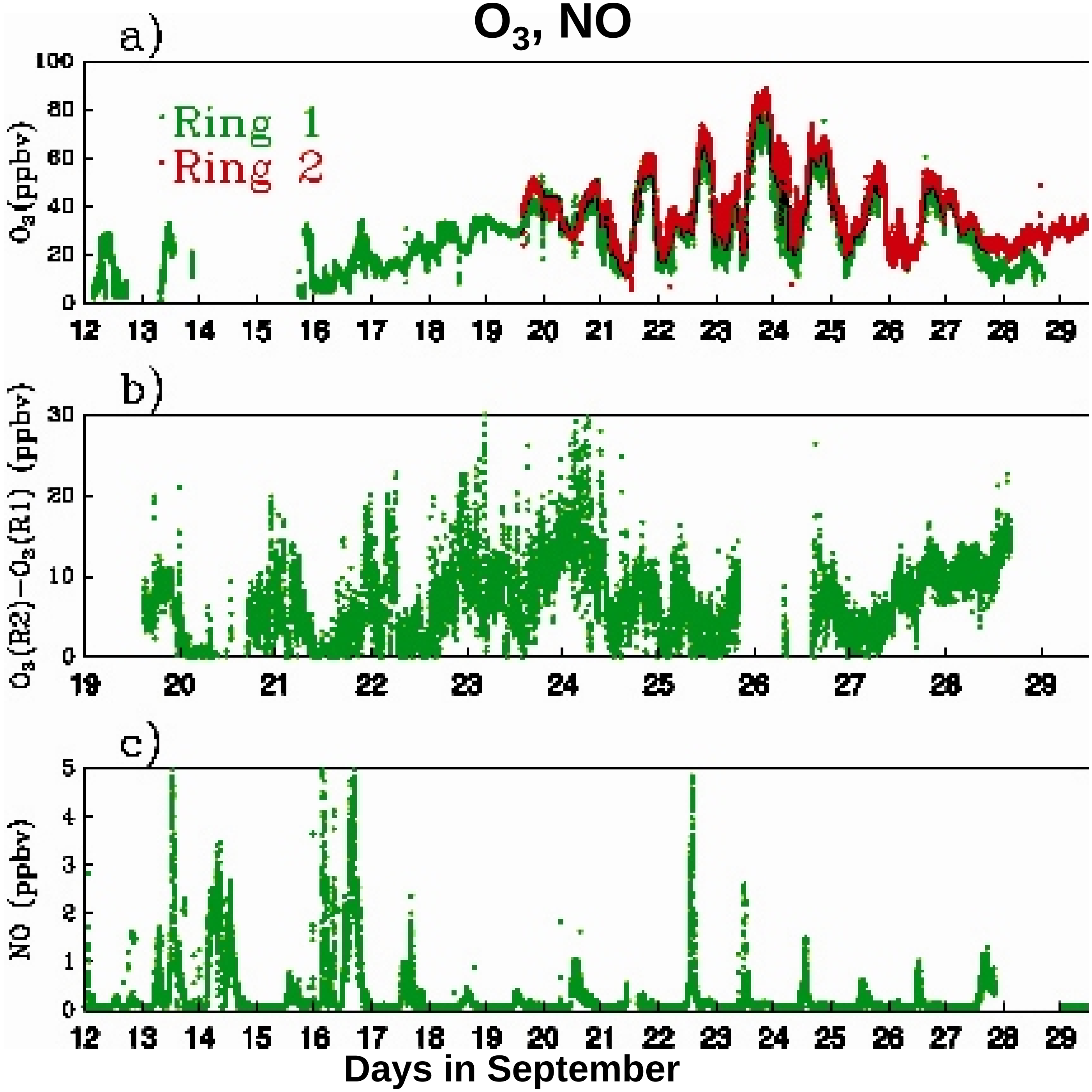
Propane & camphene emissions fluxes were ~150% higher from wet (soaked) compared to dry soils.

β-pinene emission was equal to its flux from Sweetgum (10% of Loblolly).

Soils were both a net source and sink of CH_3Br and CH_3Cl.

No significant difference for any trace gas between the present versus future CO_2 conditions.

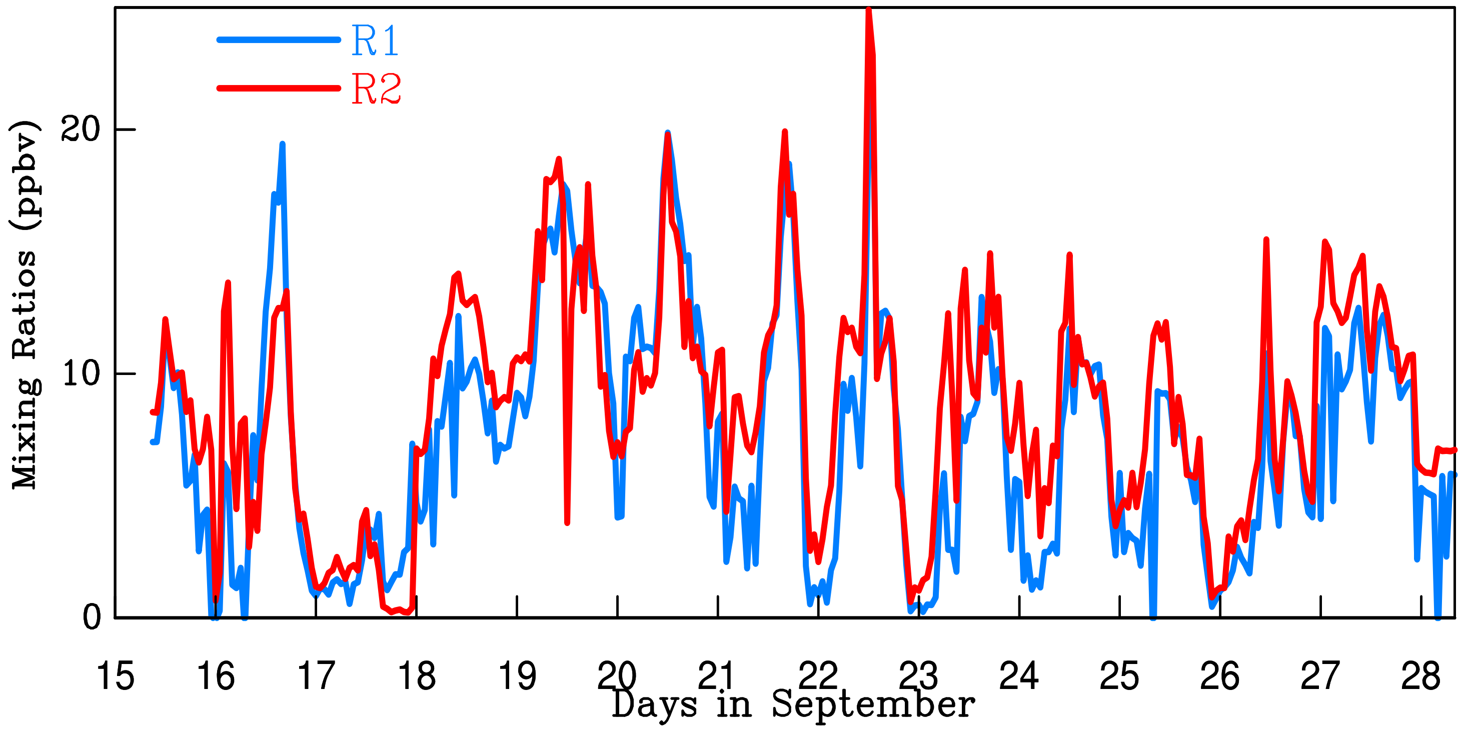
O_3, NO



R2-R1:

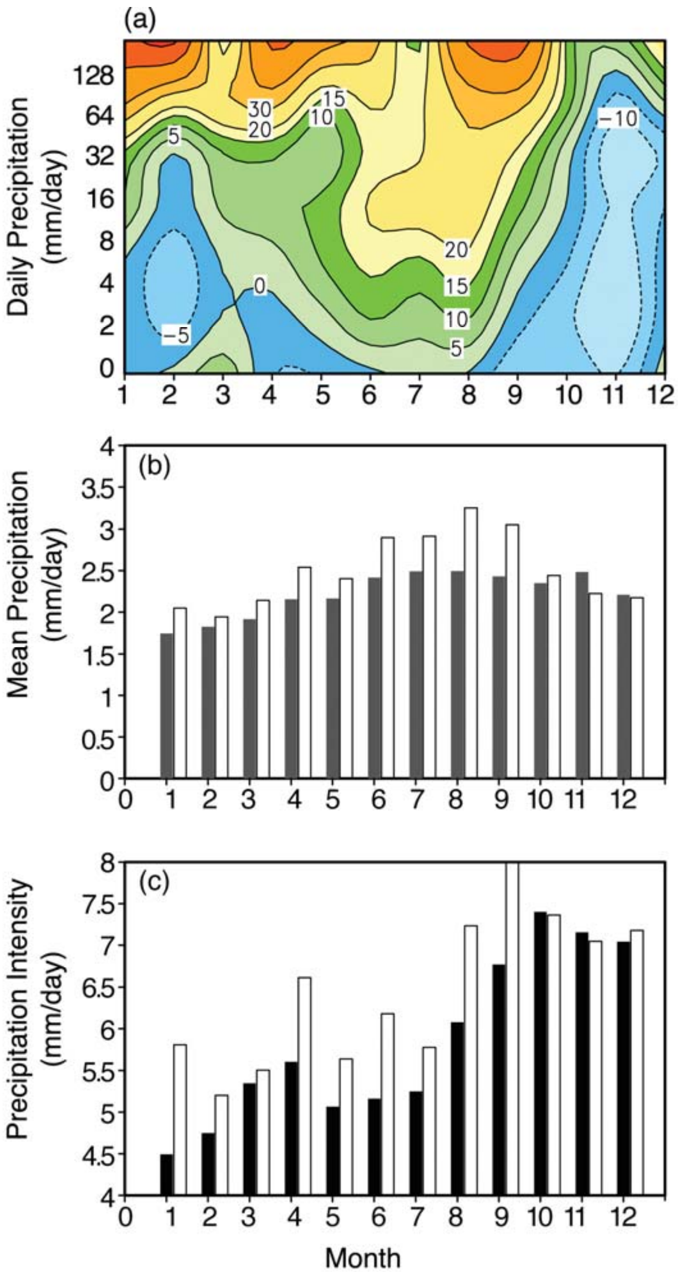
6.4±5.5 ppbv

MM Simulated O_3 Mixing Ratios



1. Box model results show that O_3 levels in Ring 2 were increased by 2.4 ppbv±2.0 ppbv on average.
2. Ozone uptake by vegetation was increased in Ring 2 by 0.5±0.3 ppbv hr^{-1} on average compared to Ring 1 using the sap flux measurements.
3. Overall, model only captured 37% of the observed O_3 increases in Ring 2. Compounds are missing from our VOC measurements that likely contributed to O_3 production. *Mao et al.* [2007]

TRACK II – Regional Climate and Air Quality Assessment



For a future climate with doubled CO_2:

1. More convective precipitation, with a higher intensity across the U.S.
2. Heavy precipitation events should become more frequent, and be distributed over fewer days with larger daily amounts.
3. The mean length of the drying period should increase from 1.78 days at present to 1.92 days, and the domain-wide maximum extended from 34 to 40 days.
4. The probability of flooding and droughts should increase in the future.

Chen et al. [2005]

CMAQ OA Module Improvement

Replacing SORGAM with MPMPO

Date (EST)	Data points	Mean Observation ($\mu g\ m^{-3}$)	Mean Prediction ($\mu g\ m^{-3}$)		MNGE		MNB	
			CACM /MPMPO	CB4 /SORGAM	CACM /MPMPO	CB4 /SORGAM	CACM /MPMPO	CB4 /SORGAM
08/03/2004	117	20.1	14.6	14.7	0.37	0.37	-0.23	-0.22
08/04/2004	117	21.0	15.1	15.3	0.38	0.39	-0.25	-0.24

Species	Data points	Mean observation ($\mu g\ m^{-3}$)	Mean prediction ($\mu g\ m^{-3}$)		Mean normalized gross error (MNGE)		Mean normalized bias (MNB)	
			CACM /MPMPO	CB4 /SORGAM	CACM /MPMPO	CB4 /SORGAM	CACM /MPMPO	CB4 /SORGAM
$PM_{2.5}$	45	16.70	13.70	14.10	0.33	0.36	-0.17	-0.15
Sulfate	44	7.13	7.98	8.55	0.52	0.60	0.32	0.39
Nitrate	44	0.28	0.19	0.18	1.34	1.23	-0.06	-0.03
Ammonium	15	2.73	2.74	2.71	0.14	0.15	0.03	0.02
EC	44	0.80	0.39	0.39	0.52	0.52	-0.45	-0.45
OC	44	3.82	1.26	1.18	0.66	0.69	-0.66	-0.69

Chen et al. [2006]

Future Climate Change and Its Impact on Air Quality

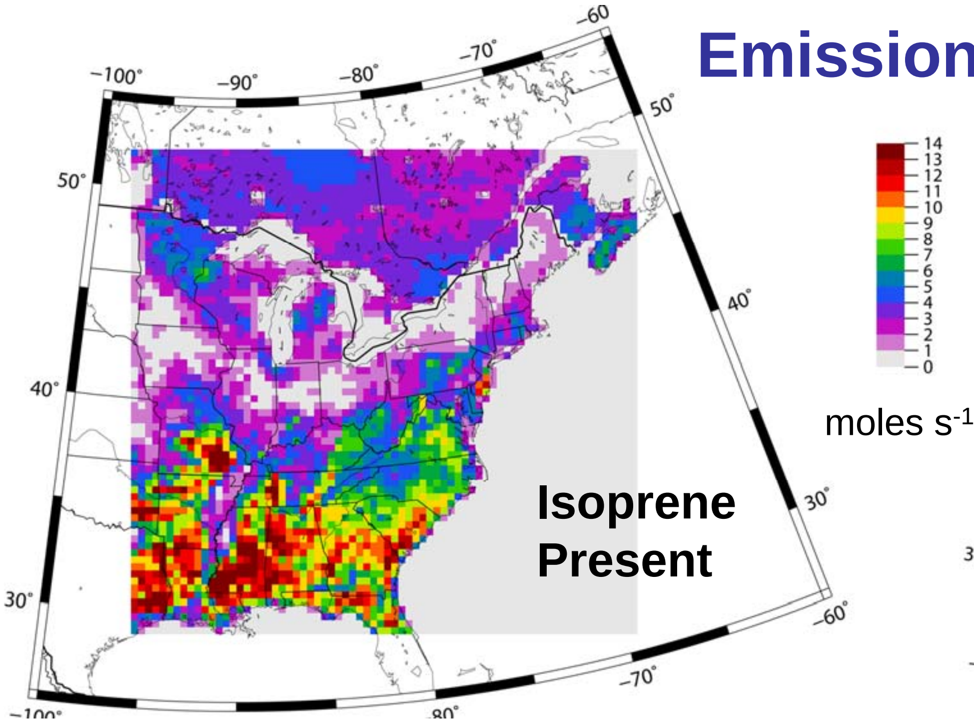
Future Projection of Global and US Emissions

IPCC A2	2000	2090	**Change (%)**
VOCs (Tg yr^{-1})	141	309	**120**
NO_x (Tg(N) yr^{-1})	32	98	**207**
VOCs (OECD90)	40	52	**29**
NOx (OECD90)	13	18	**38**

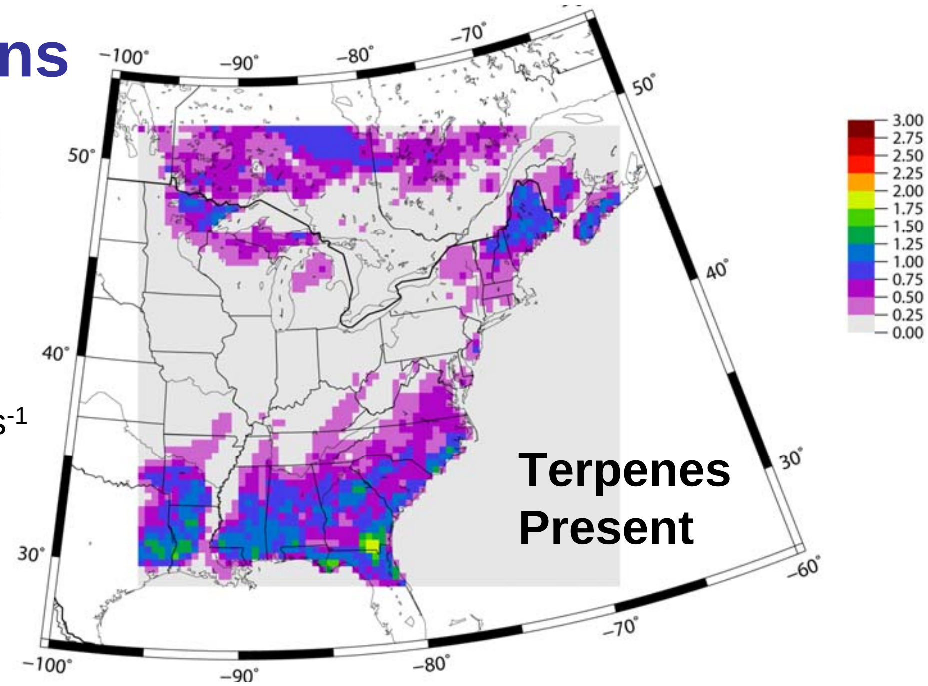
Simulations

	Present	Future-F1	Future-F2	Future-F3	Future-F4
Climate	P	F	F	F	P
Emissions	P	F	F	P	F
BC	P	F	P	F	F

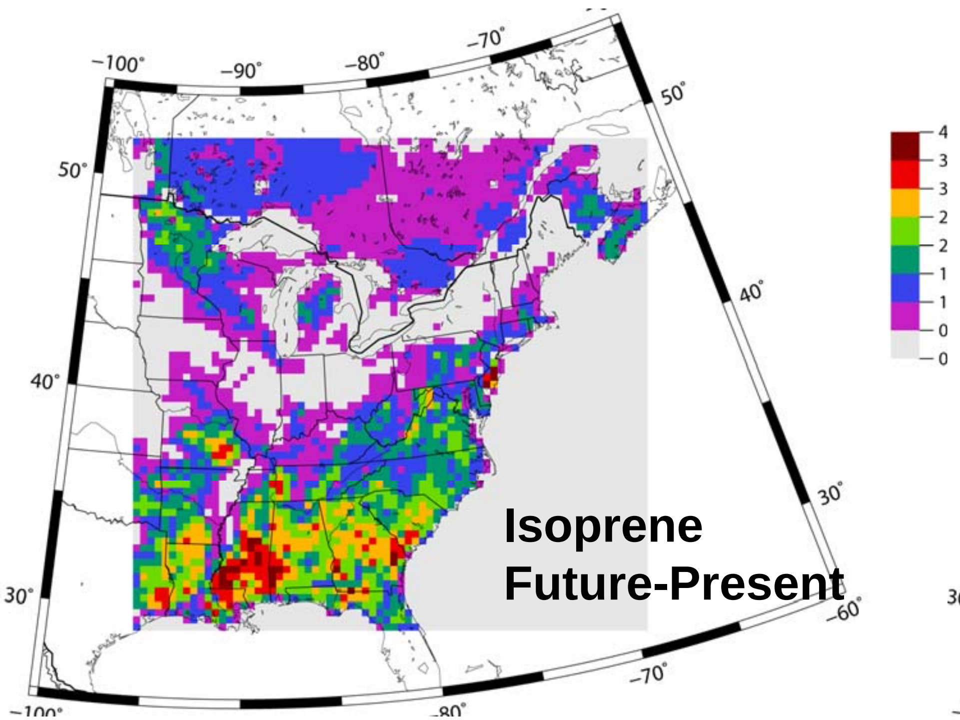
Emissions



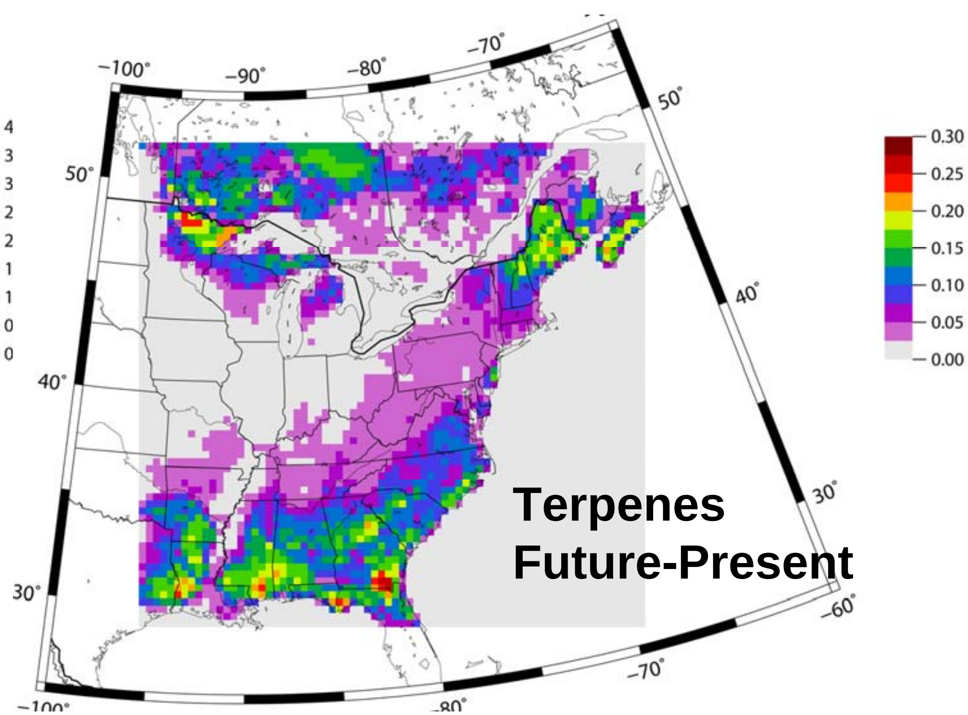
Isoprene
Present
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
moles s-1



Terpenes
Present
3.00 2.75 2.50 2.25 2.00 1.75 1.50 1.25 1.00 0.75 0.50 0.25 0.00

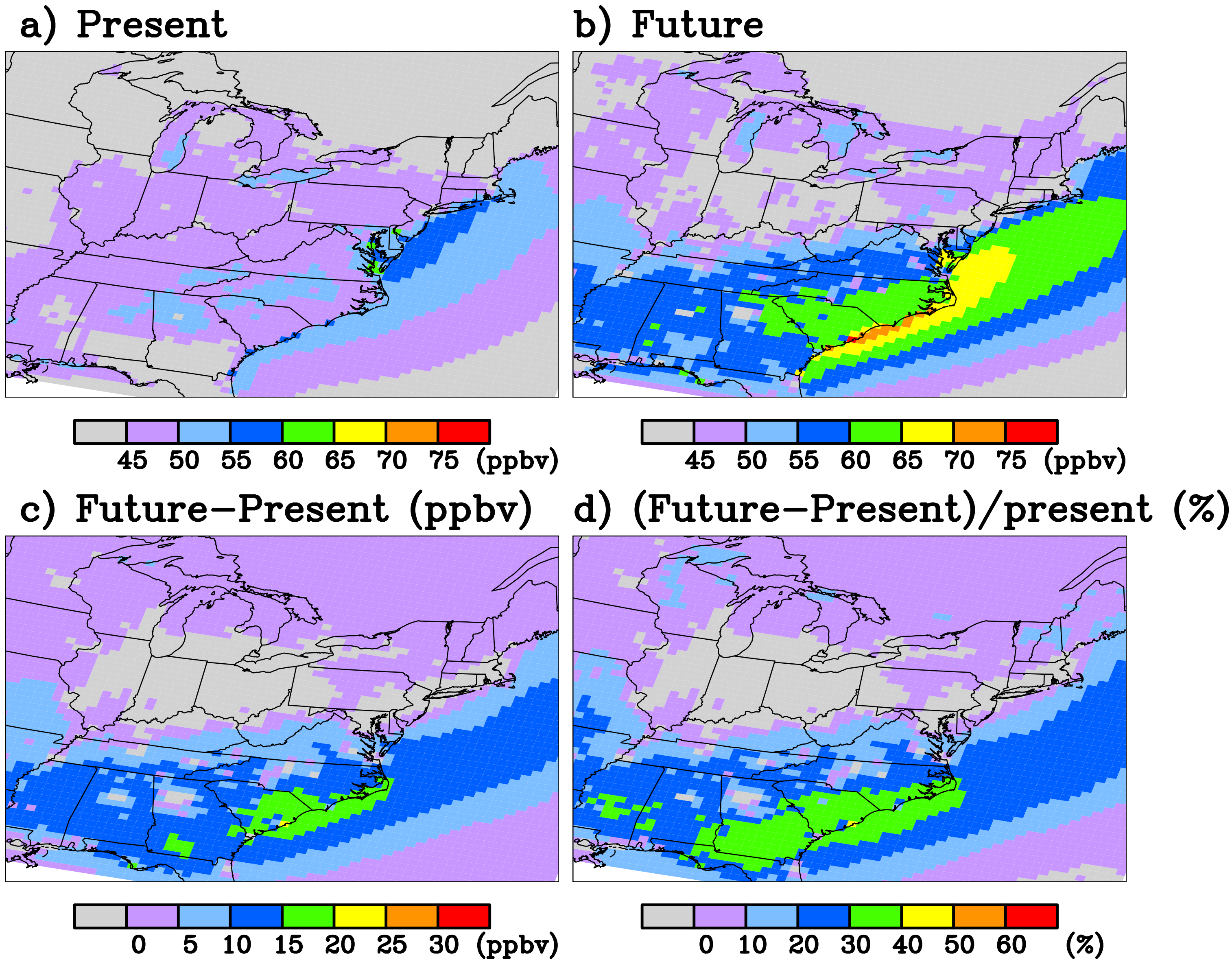


Isoprene
Future-Present
4 3 3 2 2 2 1 1 0 0

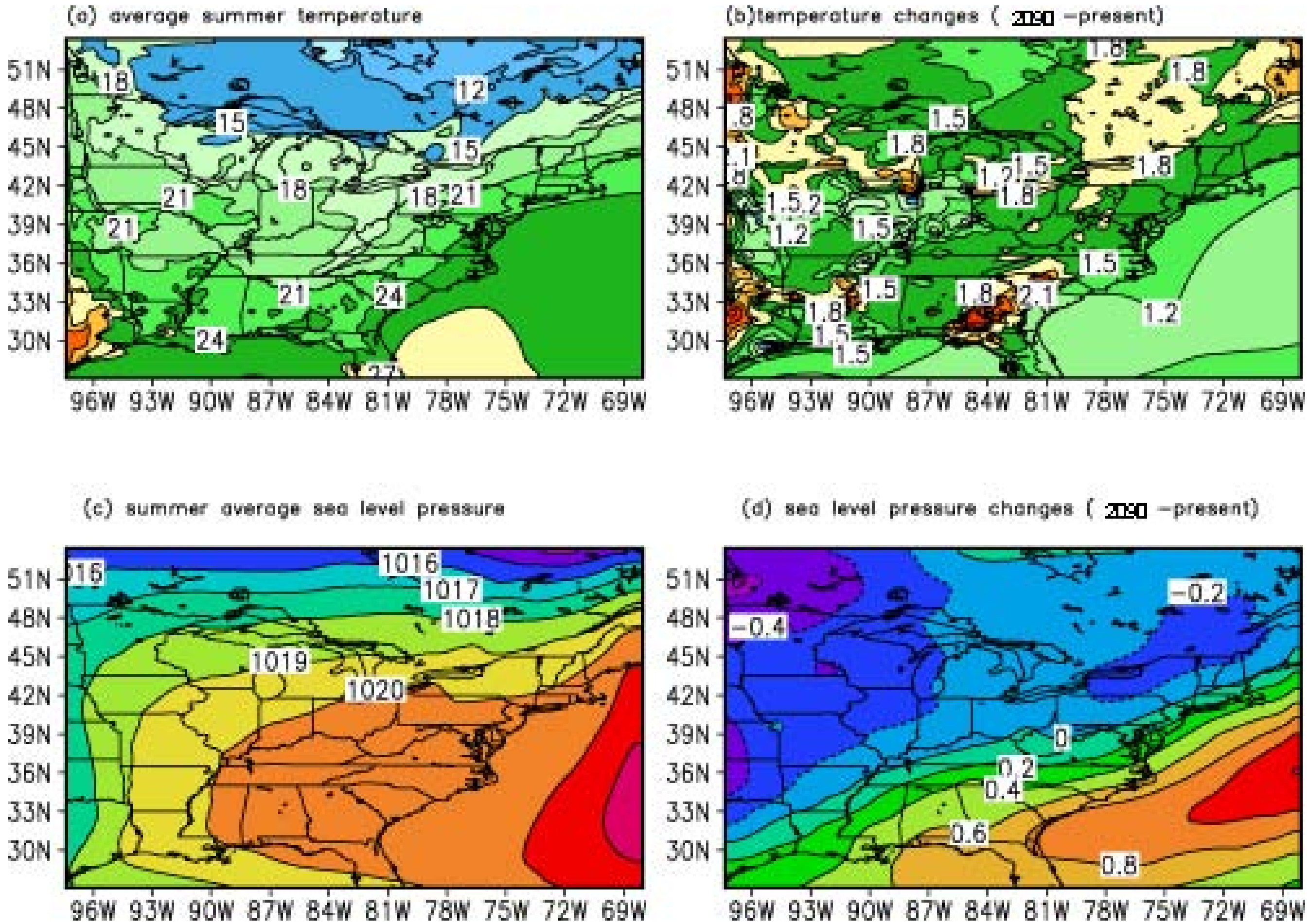


Terpenes
Future-Present
0.30 0.25 0.20 0.15 0.10 0.05 0.00

Seasonal Mean Daily Maximum 8h-O_3 Levels



Average Mean Temperature and Surface Pressure Levels



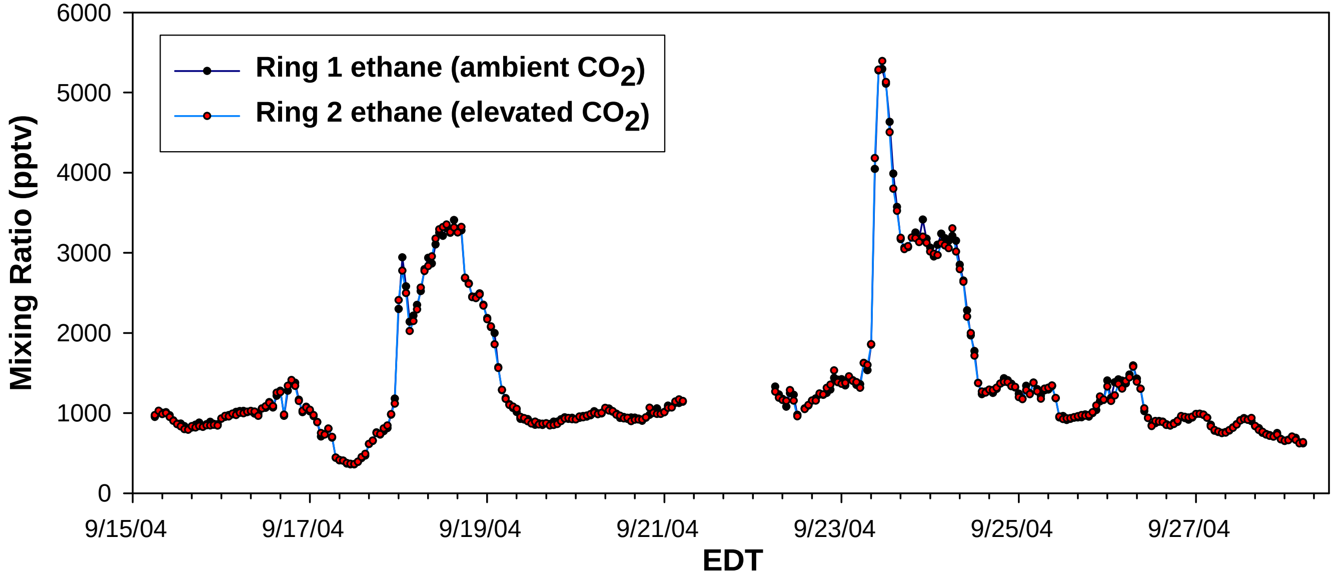
The area of largest increases in O_3 coincides with that of positive pressure changes in spite of uniform increases in anthropogenic O_3 precursors.

Future Work

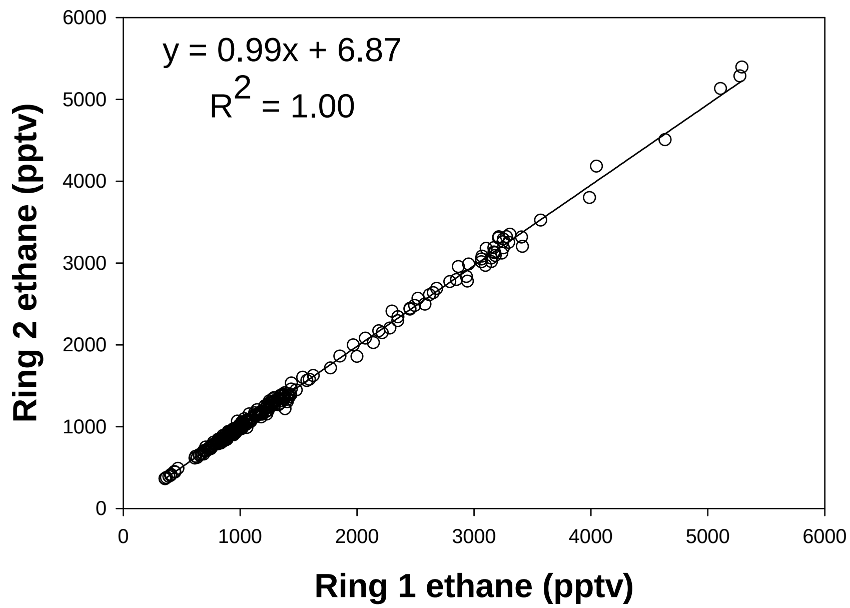
- Estimate the changes in O_3 by implementing the changes in measured biogenic emissions into the air quality modeling system.
- Complete the remaining scenarios for future climate and air quality assessment.
- Quantify the impact of climate change-induced vegetation shifts on biogenic emissions with subsequent effect on air quality.

Acknowledgement

- Laura Cottrell
- Peiter Beckman
- Tod Hagen
- All graduate students and technicians from Climate Change Research Center that participated in the project.



Ring 1 ethane (ambient CO_2)
Ring 2 ethane (elevated CO_2)
Mixing Ratio (pptv)
6000
5000
4000
3000
2000
1000
0
9/15/04
9/17/04
9/19/04
9/21/04
9/23/04
9/25/04
9/27/04
EDT



y = 0.99x + 6.87
R^2 = 1.00
Ring 2 ethane (pptv)
6000
5000
4000
3000
2000
1000
0
Ring 1 ethane (pptv)