

Equivalence in OC and EC between Single- and Multi-wavelength Carbon Analyzers

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Objectives

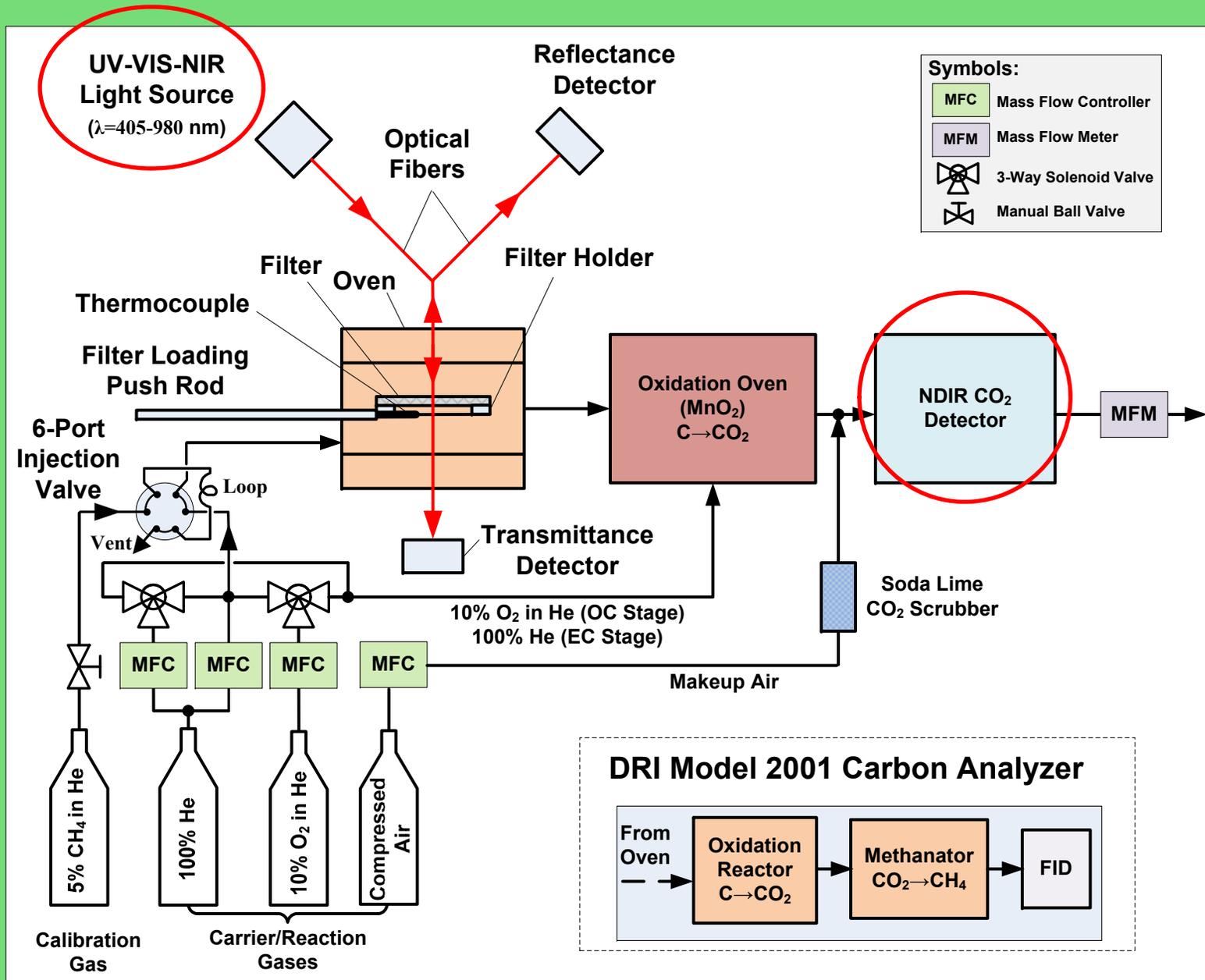
- Introduce the DRI Model 2015 Thermal/ Optical Carbon Analyzer
- Demonstrate the equivalence in OC and EC between Models 2001 and 2015
- Discuss follow-up and future plans



Motivations

- Improve efficiency
- Provide more information at lower cost
- Apply multiwavelength R and T to separate brown from black carbon
- Permit flexibility for further enhancements

Model 2015 Thermal/Optical Analyzer



Enhancements in Model 2015

- From single wavelength ($\lambda=633$ nm) to 7λ (405–980 nm)
- **Replace customized with off-the-shelf parts** (e.g., circuit boards)
- **Increase stability and reliability** (e.g., rotameter → mass flow controller; and AC → DC heater)
- **Provide easier operation and maintenance** (e.g., eliminate H₂, and Ni catalyst methanator; provide pull-out drawer for maintenance)
- **Reduce cost** (e.g., HeNe laser → diode lasers; FID → NDIR, and less hardware) **and laboratory footprint** (by ~35%)

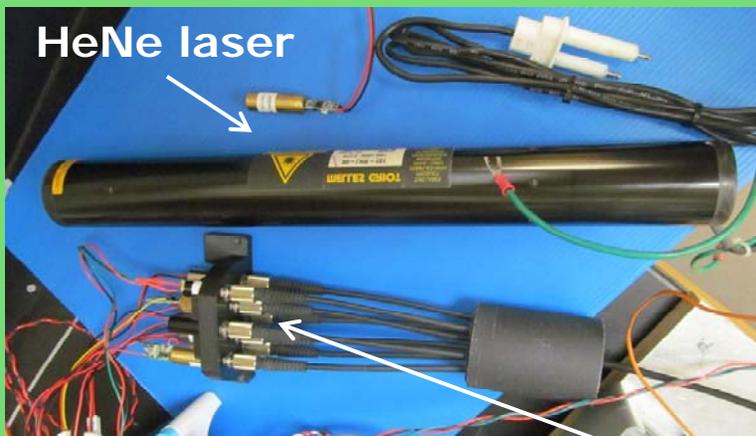
Model 2015 uses the same heating system and light pipes as Model 2001 to retain OC/EC consistency

Component	Model 2001	Model 2015
Light Source	633 nm HeNe laser	405, 445, 532, 635 , 780, 808, and 980 nm diode lasers
Fiber optic	bifurcate fibers (bundle)	8-leg fibers (single)
Sample oven	One arm	Branched side arm
Flow control	Rotameters	Mass flow controllers
Sample oven power supply	110 V AC	DC
Circuit boards	Custom made	Generic/Programmable
Detector	FID (CH ₄) detection (requires ultrapure H ₂)	NDIR (CO ₂) detection (no H ₂)
Conversion after thermal evolution	Oxidization (to CO ₂) and reduction (to CH ₄)	Oxidation (to CO ₂)
Data acquisition	Keithley	National Instruments
Software	Visual Basic/C+	LabVIEW

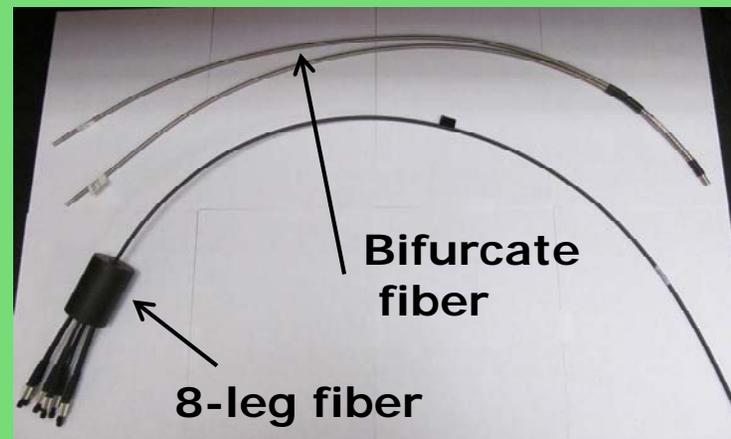
Components Comparison

(Model 2015 components on the bottom of each picture)

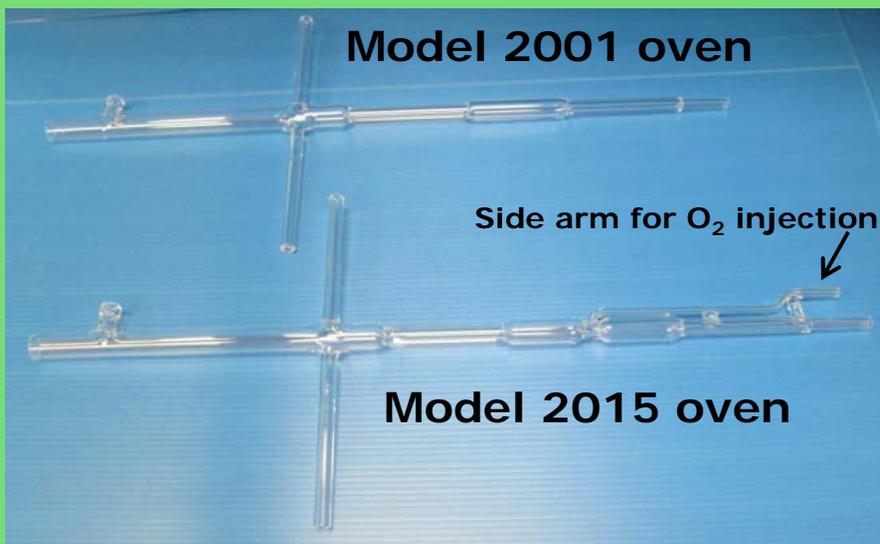
Laser



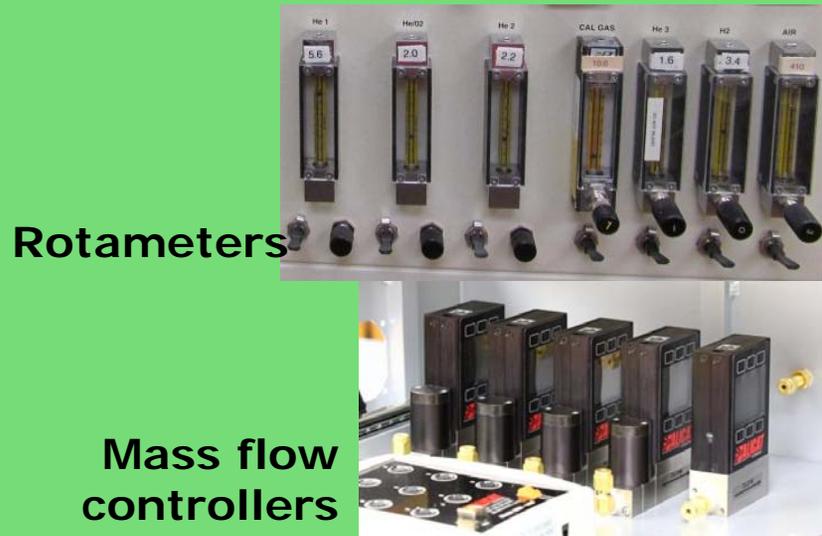
Fiber Optics



Oven



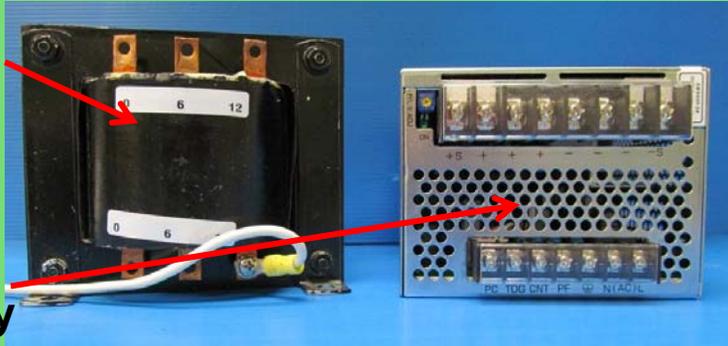
Flow Control



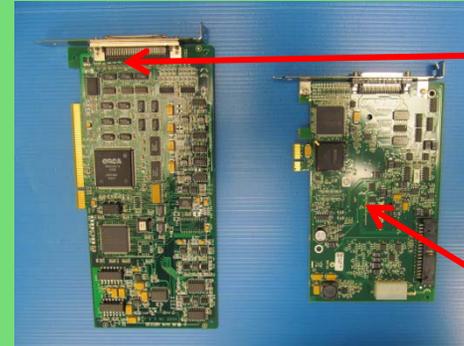
Components Comparison (cont.)

(Model 2015 components on the right of each picture)

AC transformer



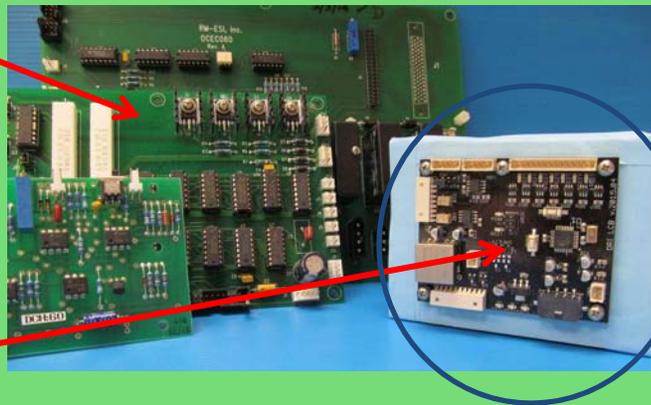
DC power supply



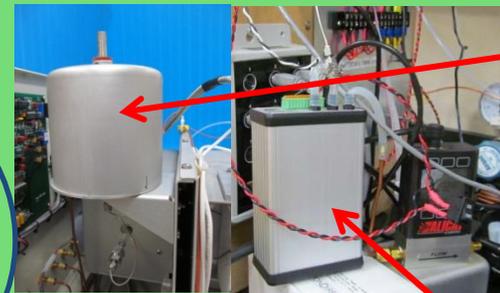
Keithley data acquisition card

National Instruments data acquisition card

Custom circuit boards



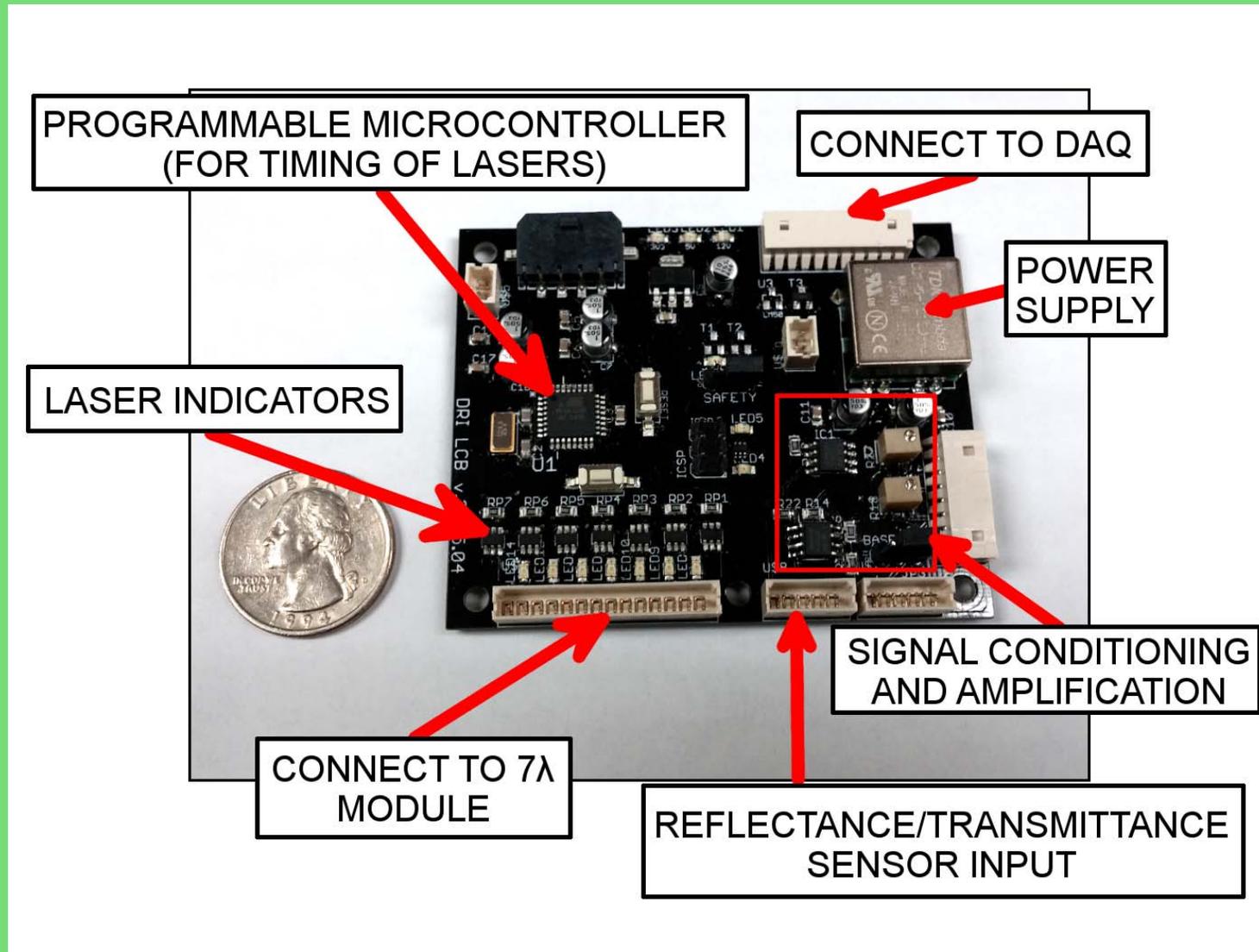
Programmable board



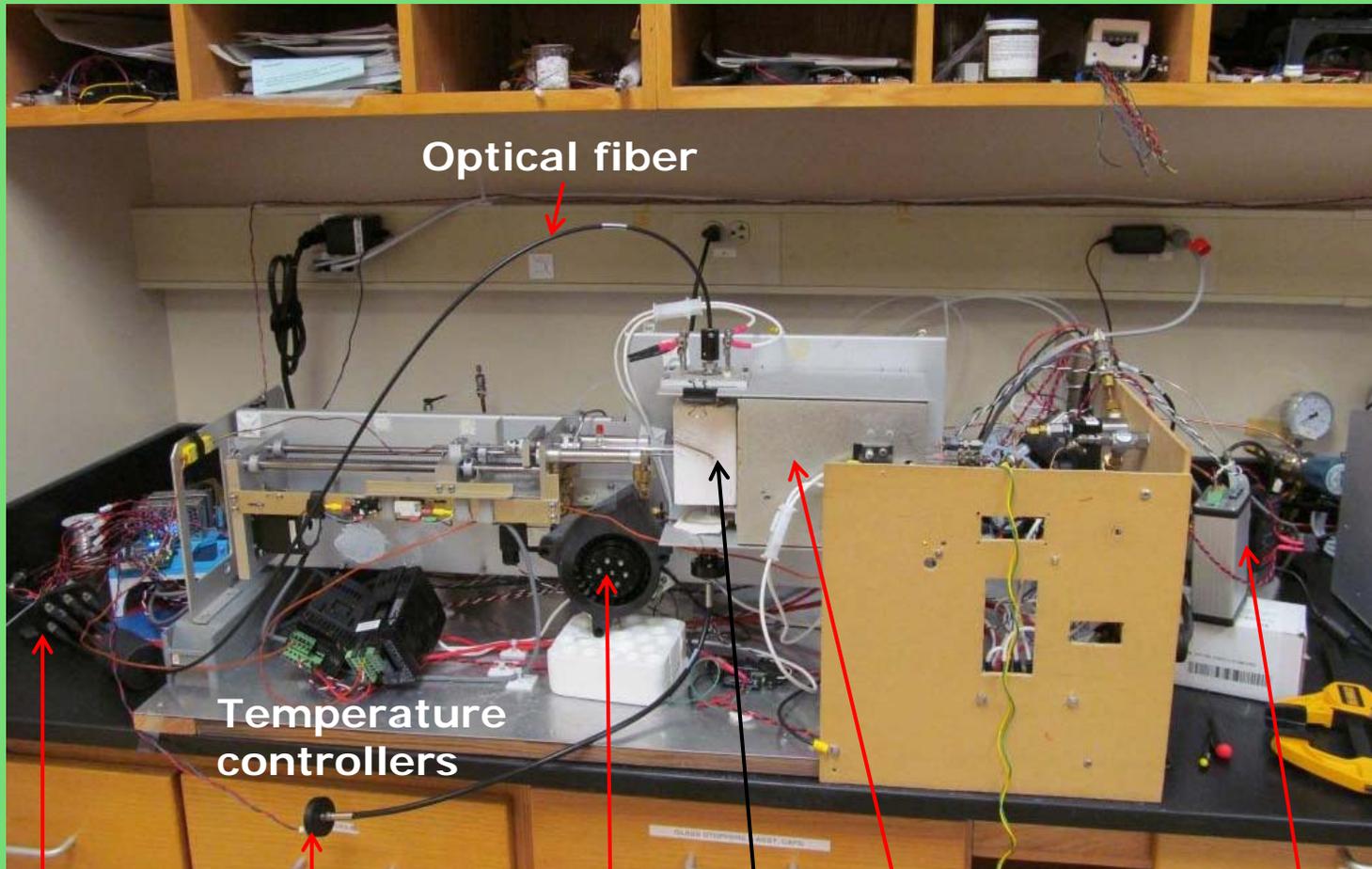
Flame ionization detector (FID)

Non-dispersive Infrared Detector (NDIR)

A small microcontroller coordinates the signal creation and detection



Samples were analyzed on the prototype Model 2015



Optical fiber

Temperature
controllers

Lasers

Transmittance
photodiode

Cooling fan

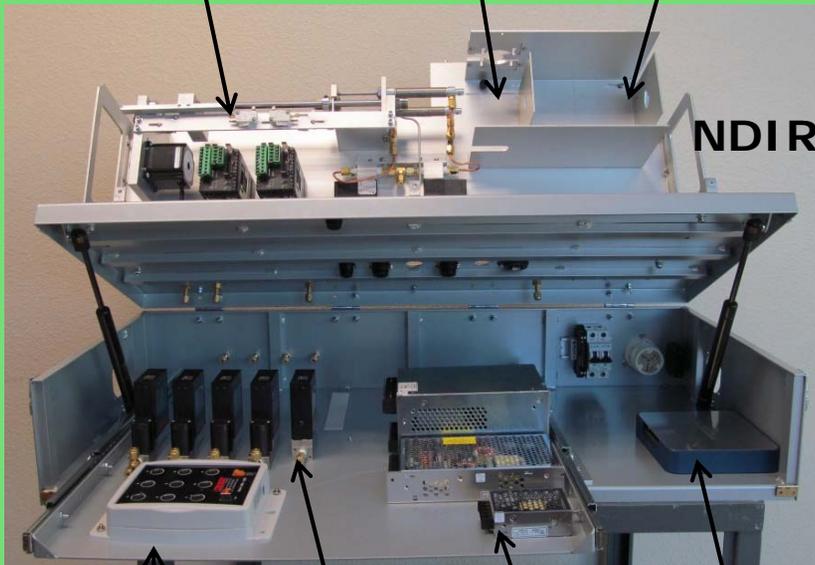
Sample
oven

Oxidation oven

NDIR

New Model 2015 is under construction

Temperature controllers Sample oven Oxidation oven



With pull-out drawer for maintenance

Mass flow controllers Power supplies

Mass flow communications Data acquisition card



Main Operation Screen for Model 2015

(User-Friendly LabVIEW)

DRI Model 2015 Thermal/Optical Analyzer

Autoscan
 No
 True if Last Run Fully Written to DB
 Writing to DB

Sample Details

Project Name	NCA17
Batch	BATCH07
Sub-Batch	2014
Sample ID	SDKQ0520
Run No.	3
Punch No.	.53
Filter Deposit Area	1
Technician	MU

For gas calibration, baking & autocalib



Press to Enter/Change Sample Info

- Parameter Settings
- Manual Adjustments
- Temperature Control

System Status

Status	Acquiring Laser Baseline: 11 of 3
Sample Oven Position	ANALYZE
Sample Oven Temperature	60.4
Oxygenator Temperature	907.8
NDIR Reading	1.4

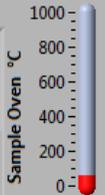
ADVMeasurements
ADVIntegral
Graphs
ProtocolDetails
Troubleshooting
AnalysisResults

Temperatures

Components

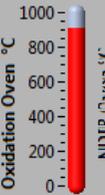
- Sample Heater
- Oxygenator Heater
- Flow Controllers
- NDIR

Sample Oven °C



55 °C

Oxidation Oven °C



912 °C

NDIR Oven °C



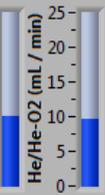
Flow Rates

He (mL / min)



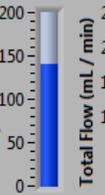
40

He-2 (mL / min)



10

He/He-O2 (mL / min)



10

Makeup Flow (mL / min)



140

Total Flow (mL / min)



Reflectance

640
216
517
334
382
639
435

Transmittance

243
116
219
57
247
186
48

Pressure Signal

4.9

NDIR Digital

1.4

NDIR Analog

1.5

NDIR Base

0.495

FrontValve

BackValve

LeakValve

LOAD

CAL1

CAL2

ANA

CVInject

OpenBreech

Fan ON

Status

Acquiring Laser Baseline: 12 of 30

NDIR Output

M 43839 43829 1.429 54.7 0.000 0.000 862 54.3 55.2

 **START**

 **Abort Run**

 **Exit**

Model 2015 includes more details in “sample info” input screen

Setup

Graph

	Min	Max
T min/max	0	1000
LR min/max	0	2500
LT min/max	0	2500
F8 min/max	0	400
F6 min/max	0	50

TimeMax: 1000

FIDAutoScale On

Flagging

Flags

Comment

FID

FID_6 FID_8 FID_8_0_5

Polarity

Unipolar Bipolar

Run Information

Type: Sample

Project Name: IMPROVE

Batch #: B14

Sub-batch #: 144

Command table: CmdImproveA

Sample ID: T18262

Run #: 1

Punch area: .55

Deposit area: 3.53

Tech initials: MJ

Exit OK

Model 2001

Enter Sample Details

File Edit View Project Operate Tools Window Help

Model 2015 Sample Details

Sample Details

Project Name	NCA17
Batch	BATCH07
Sub-batch	2014
Sample ID	TBOQCF025
Run No.	4
Punch Area	.53
Filter Deposit Area	1
Technician	CAC

Analysis Protocol

C:\Labv...\Config\IMPROVE_A.pro Drying Time 90 seconds

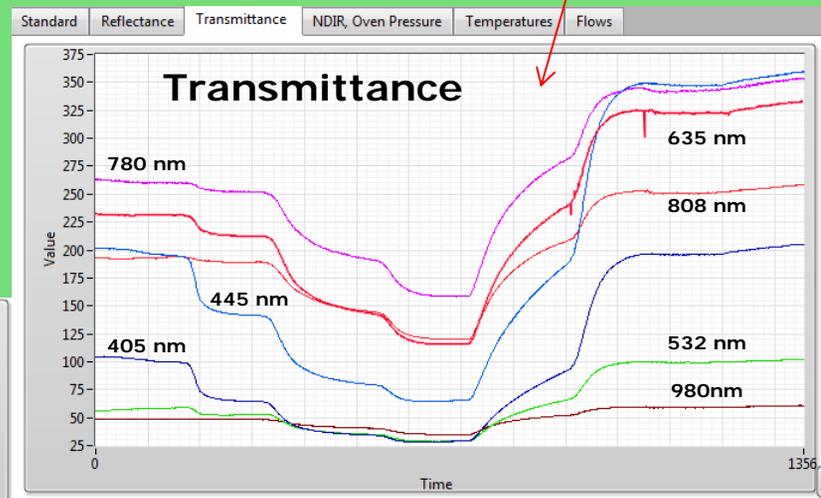
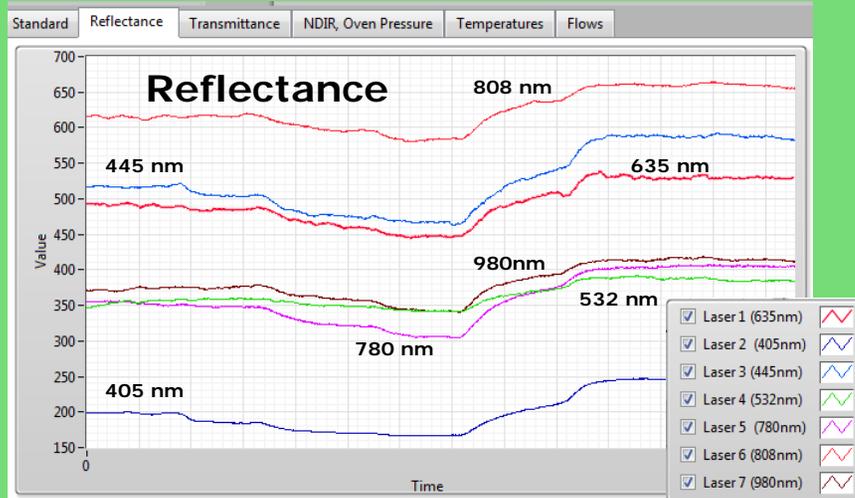
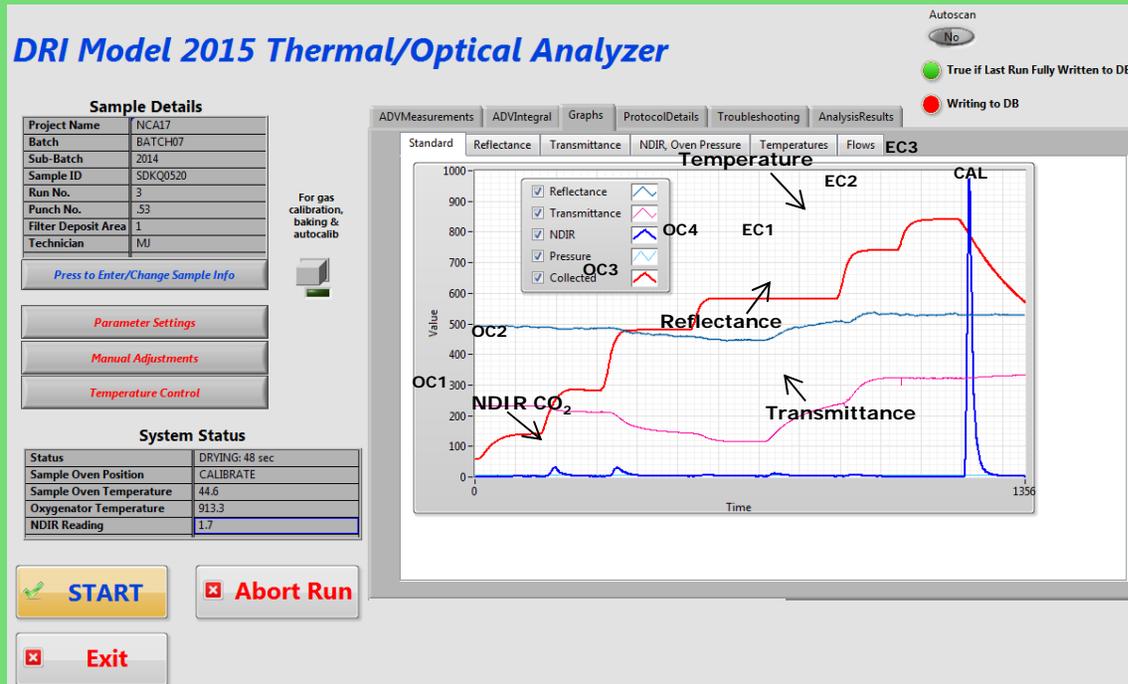
Fraction ID	Temperature	Min. Time	Max. Time	O2 Valve	Carle Valve
OC1	140	150	580	Close	Load
OC2	280	150	580	Close	Load
OC3	480	150	580	Close	Load
OC4	580	150	580	Close	Load
EC1	580	150	580	Open	Load
EC2	740	150	580	Open	Load
EC3	840	150	580	Open	Load
CAL	0	150	580	Open	Inject
END	0	0	0	Close	load

OK Save To File Load File

Model2012X VI vSG.lvproj/My Computer

Model 2015

Displays for Model 2015 show 635 nm reflectance and transmittance (Similar to Model 2001)

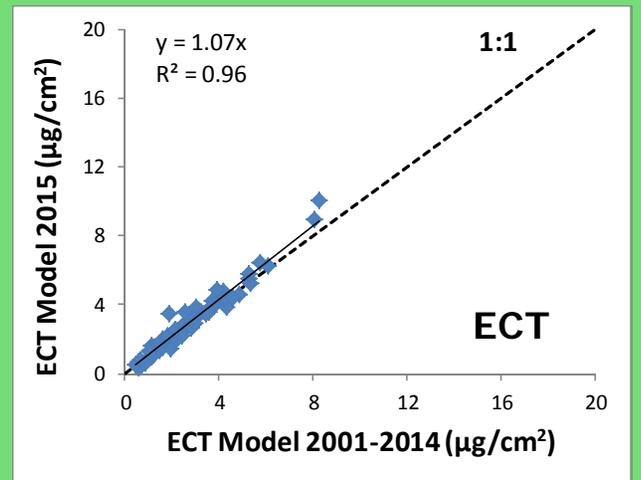
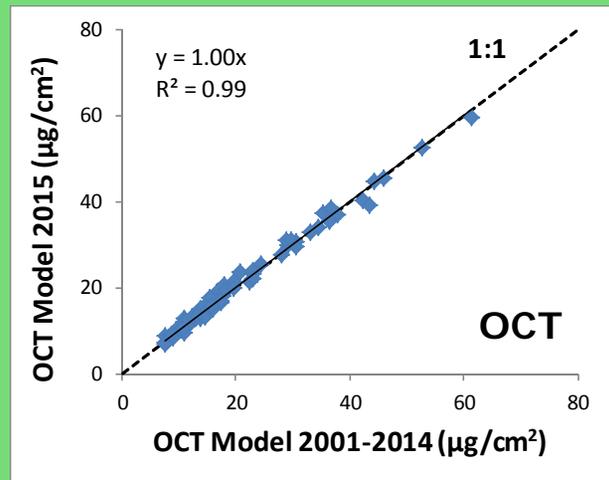
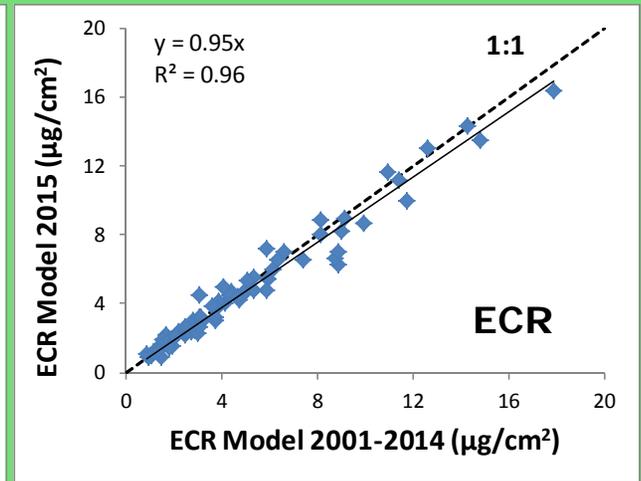
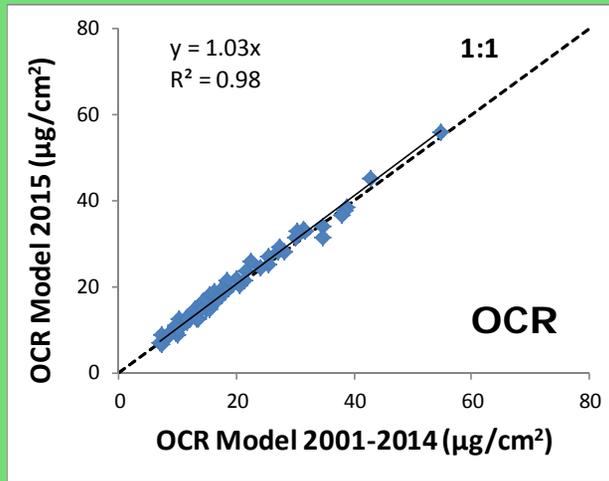
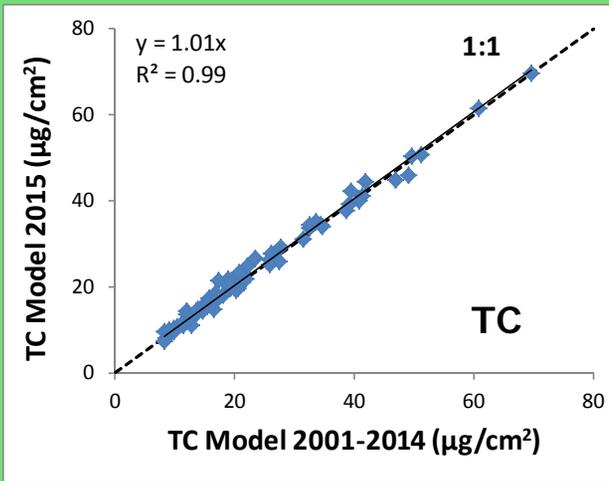


IMPROVE and urban Fresno samples* were analyzed for equivalence testing

- 73 IMPROVE-X Modules (2010-2014)
- 71 IMPROVE (2010-2013)
- 67 Fresno Supersite Samples (2003-2006)

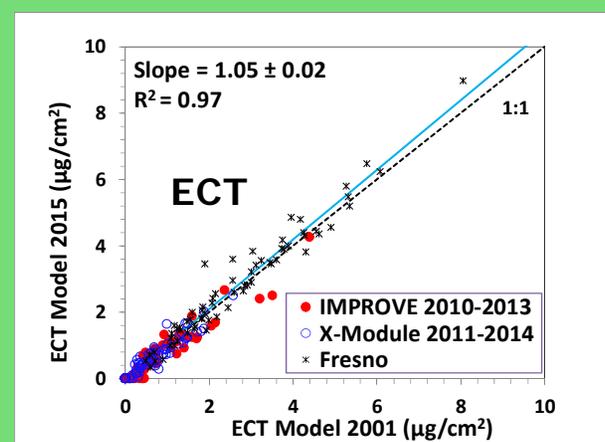
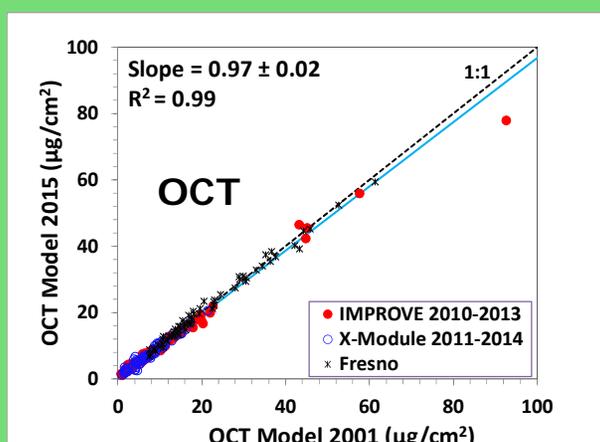
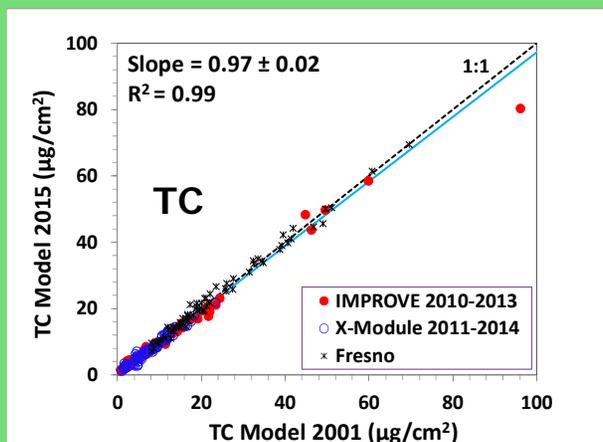
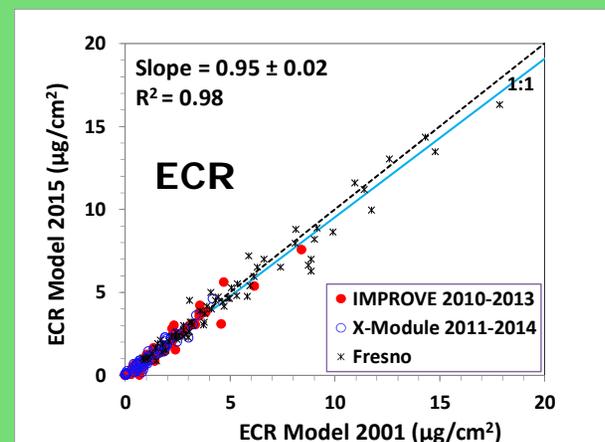
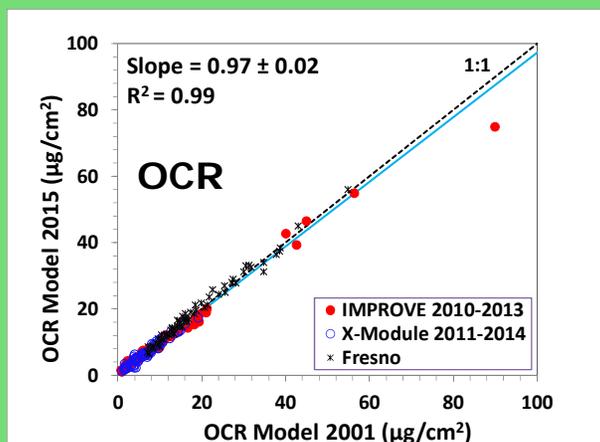
*n=211

Good equivalence is found for Fresno samples analyzed by Model 2001 and Model 2015



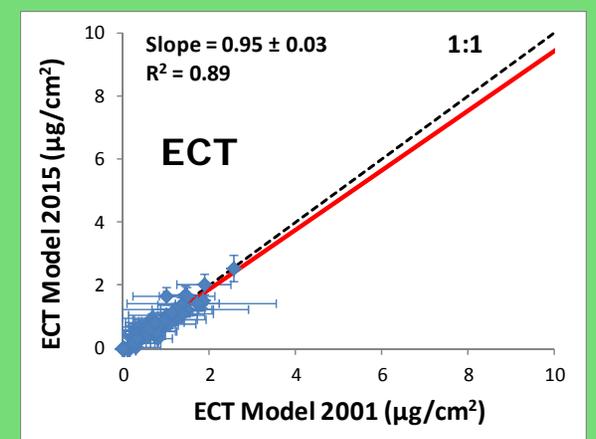
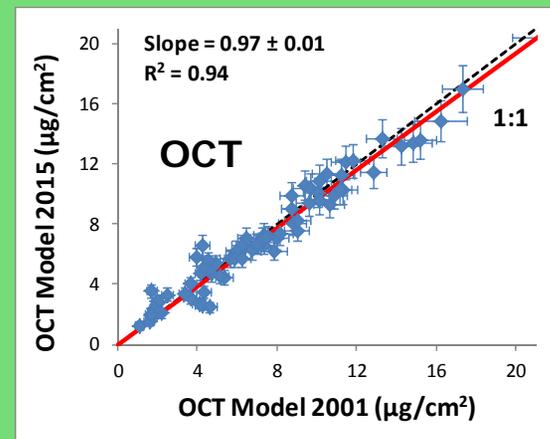
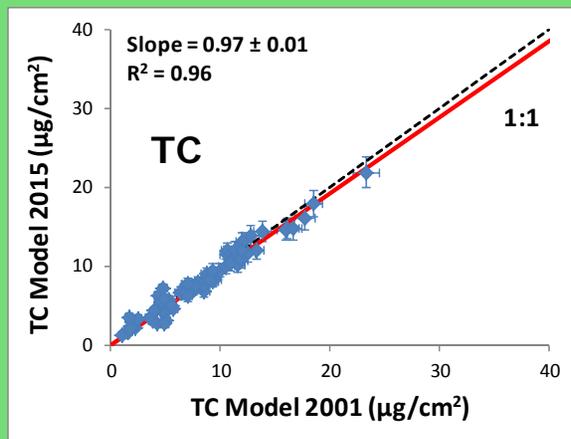
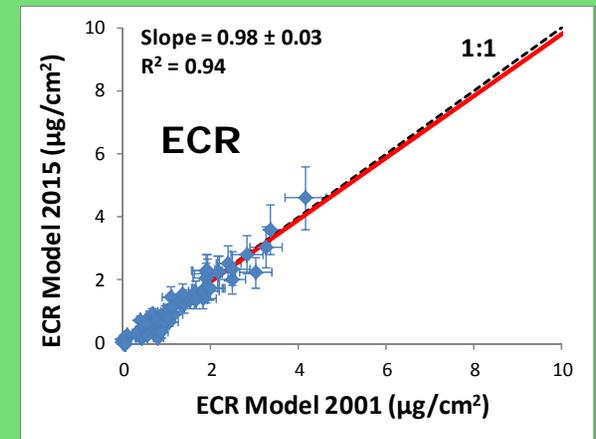
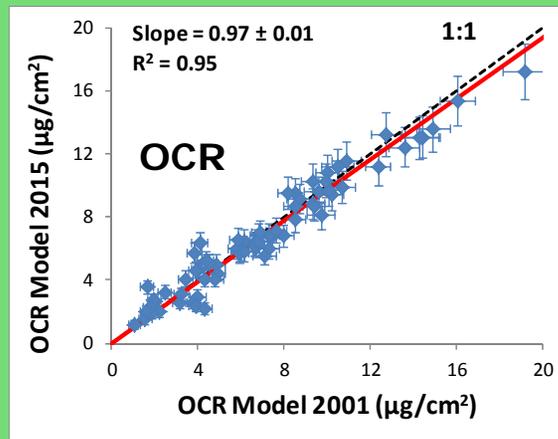
N=67

For a wide variety of samples, TC, OC, and EC compare well between model 2015 (635 nm) and Model 2001 (633 nm)



N=211 (IMPROVE 2010-2013, X-Module 2011-2014, and Fresno)

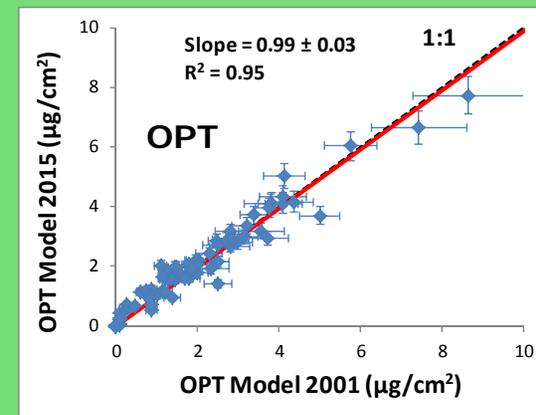
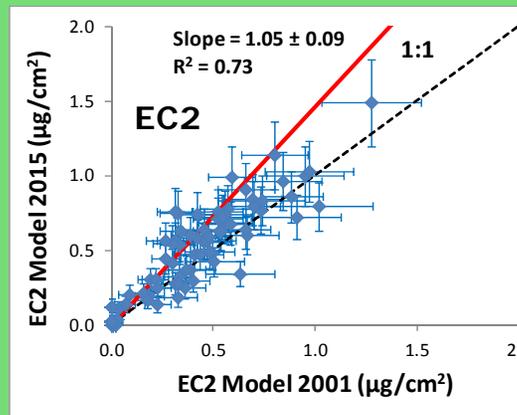
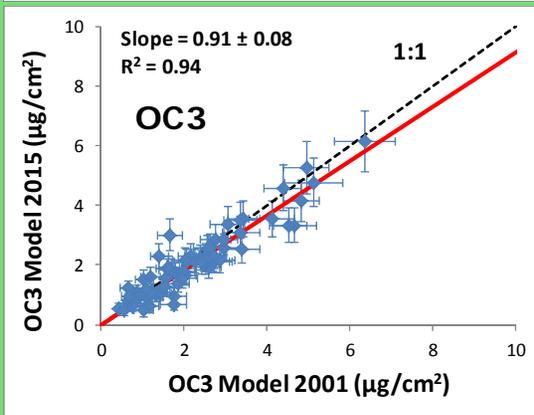
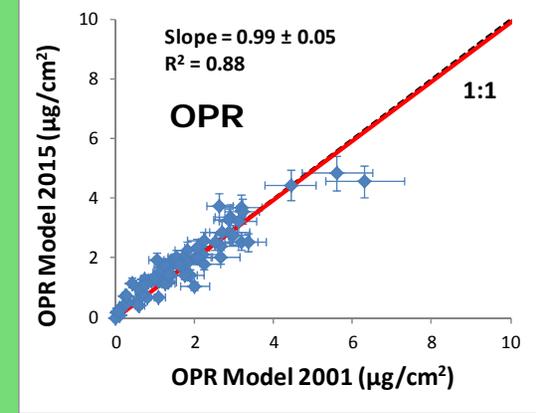
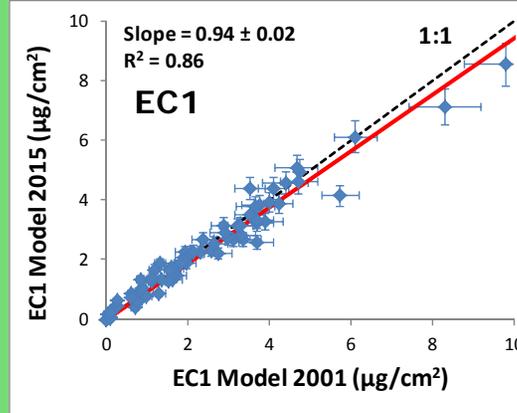
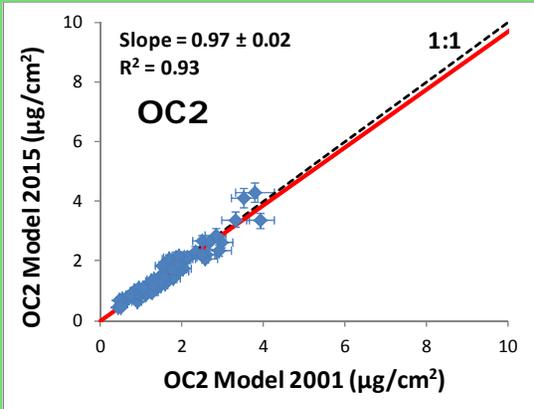
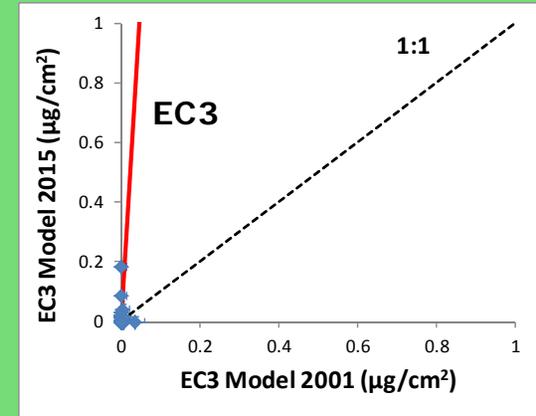
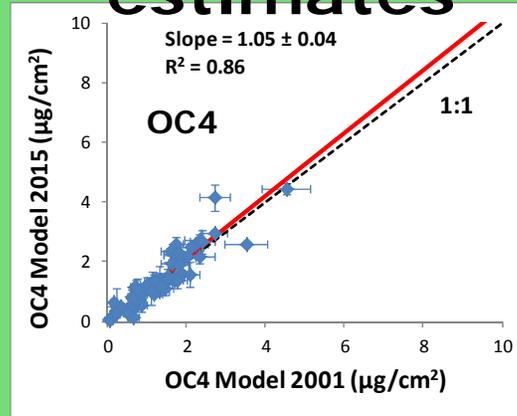
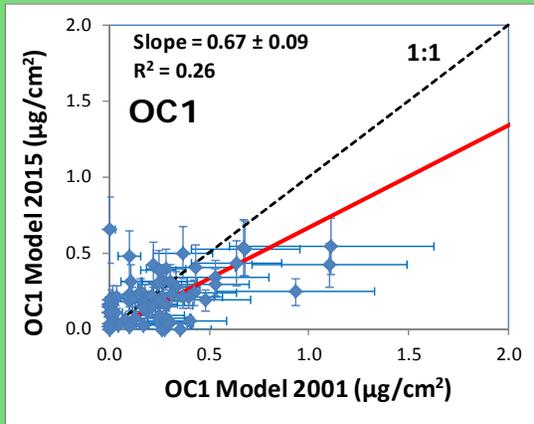
For IMPROVE samples, TC, OC, and EC are comparable for 2015 (635 nm) and Model 2001 (633 nm)



N=73 (IMPROVE X-Module 2011-2014)

Most carbon fractions are within uncertainty estimates

y - Model 2015



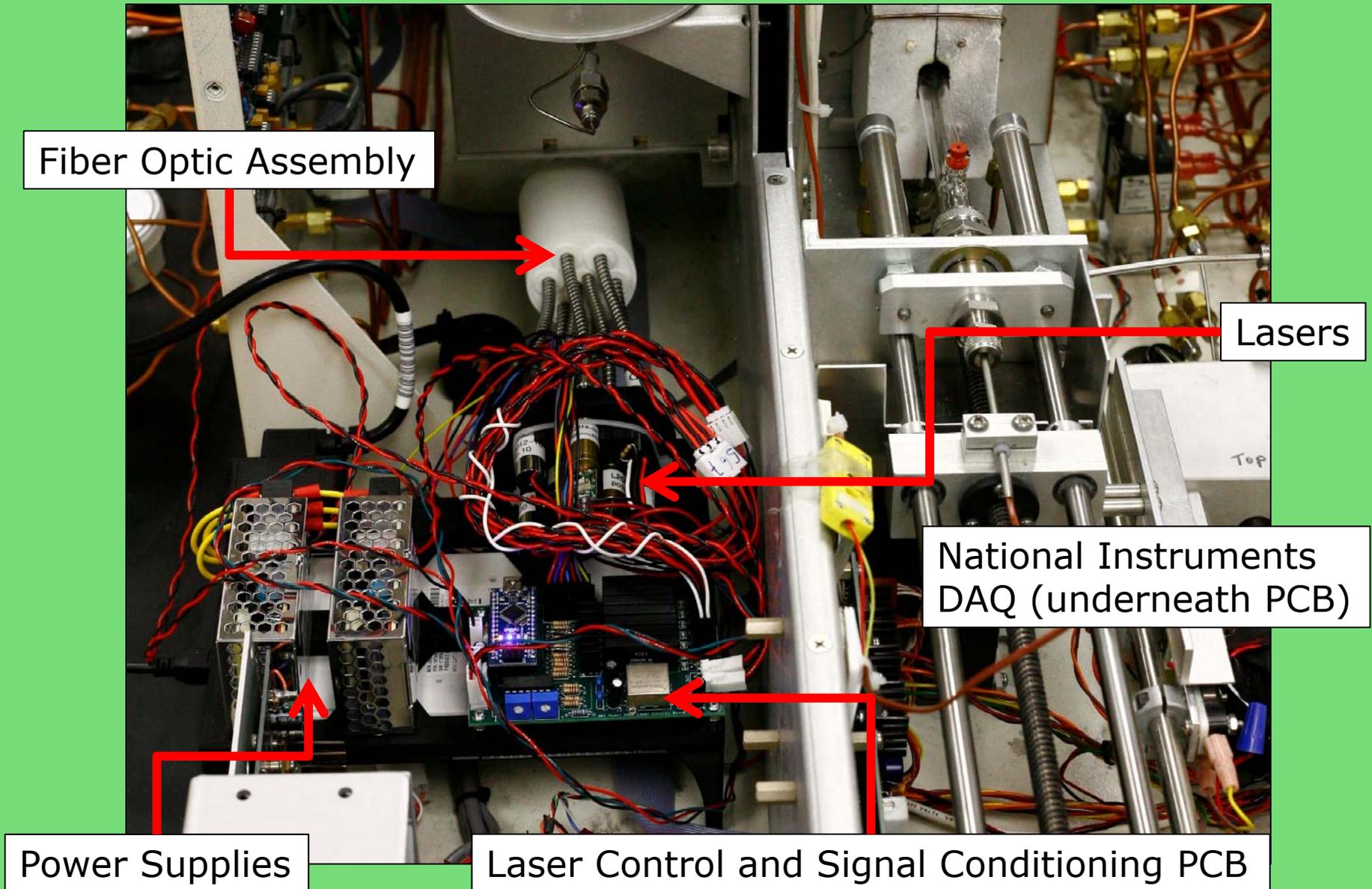
x - Model 2001

N = 73 (IMPROVE X-Modules)

Summary

- Consistency in OC and EC is found between Models 2015 and 2001 Carbon Analyzers
- Model 2015 has enhanced features with modernized components and provides additional optical characteristics

Existing Model 2001 analyzers can be retrofitted with seven-wavelength laser (Model 2001-7 λ)



Follow-up and Future Plans

- Start replicates on a growing fraction of samples with Model 2015 and Model 2001-7 λ retrofits
- Compare precisions for different units
- Prepare publication documenting equivalence
- Begin 7 λ data reporting for 2015 IMPROVE samples