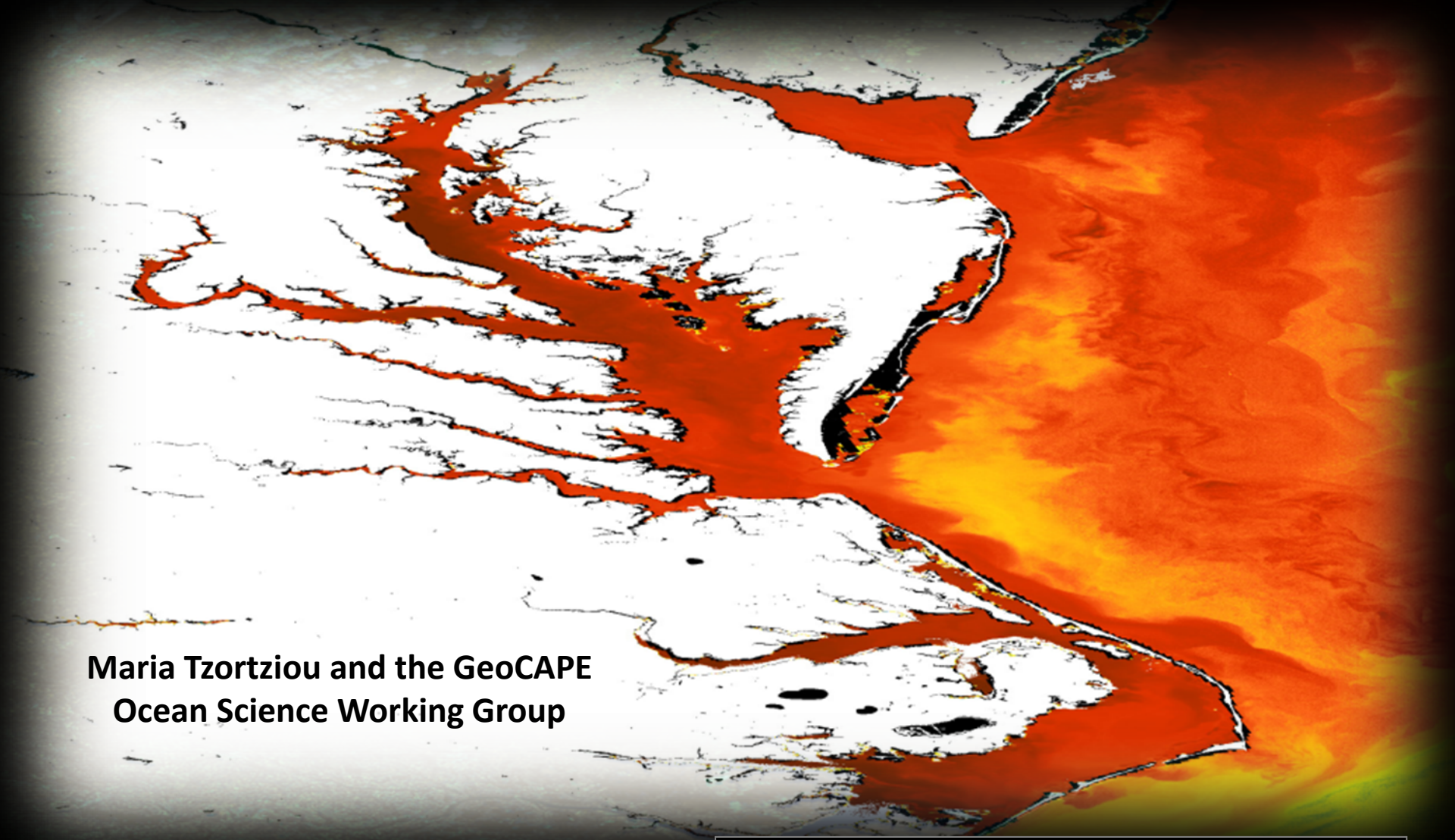
Ship measurements of Aerosols and Trace Gases in the Chesapeake Bay during the Summer 2011 DISCOVER-AQ and CBODAQ campaigns

CBODAQ: GEO-CAPE Chesapeake Bay Oceanographic campaign with Discover AQ



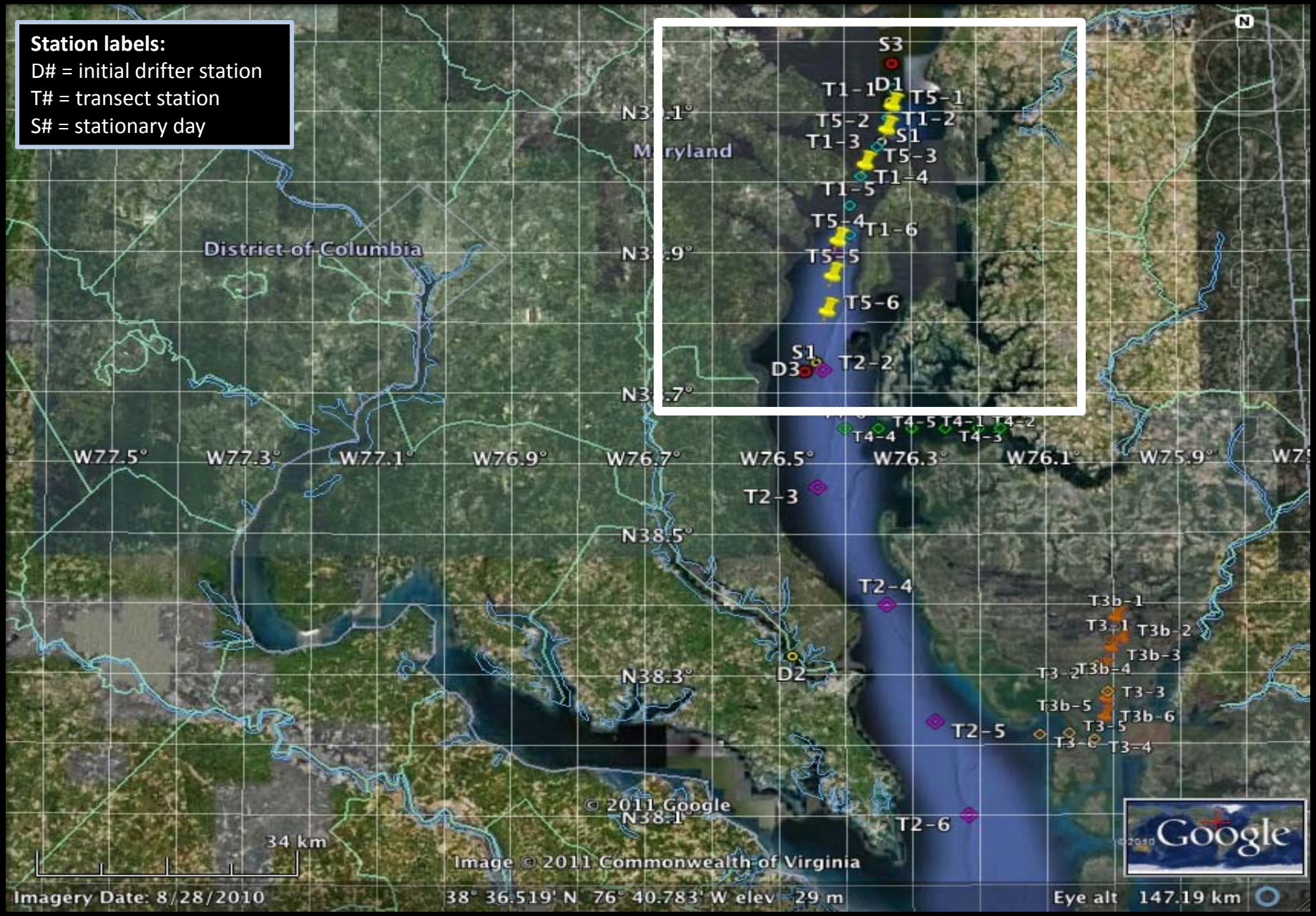
Maria Tzortziou and the GeoCAPE Ocean Science Working Group

MERIS chlorophyll (http://www.coastcolour.org/site_6.html)

NOAA Vessel SRVx - National Marine Sanctuary Test and Evaluation Vessel R8501

Co-Leads/Chief Scientists: Antonio Mannino & Maria Tzortziou
Participants: More than 25 scientists and additional students from NASA/GSFC, NOAA, University of Maryland, University of New Hampshire, University of South Florida, Old Dominion University, East Carolina University, Smithsonian Environmental Research Center, Johns Hopkins University, Sigma Space Corporation.

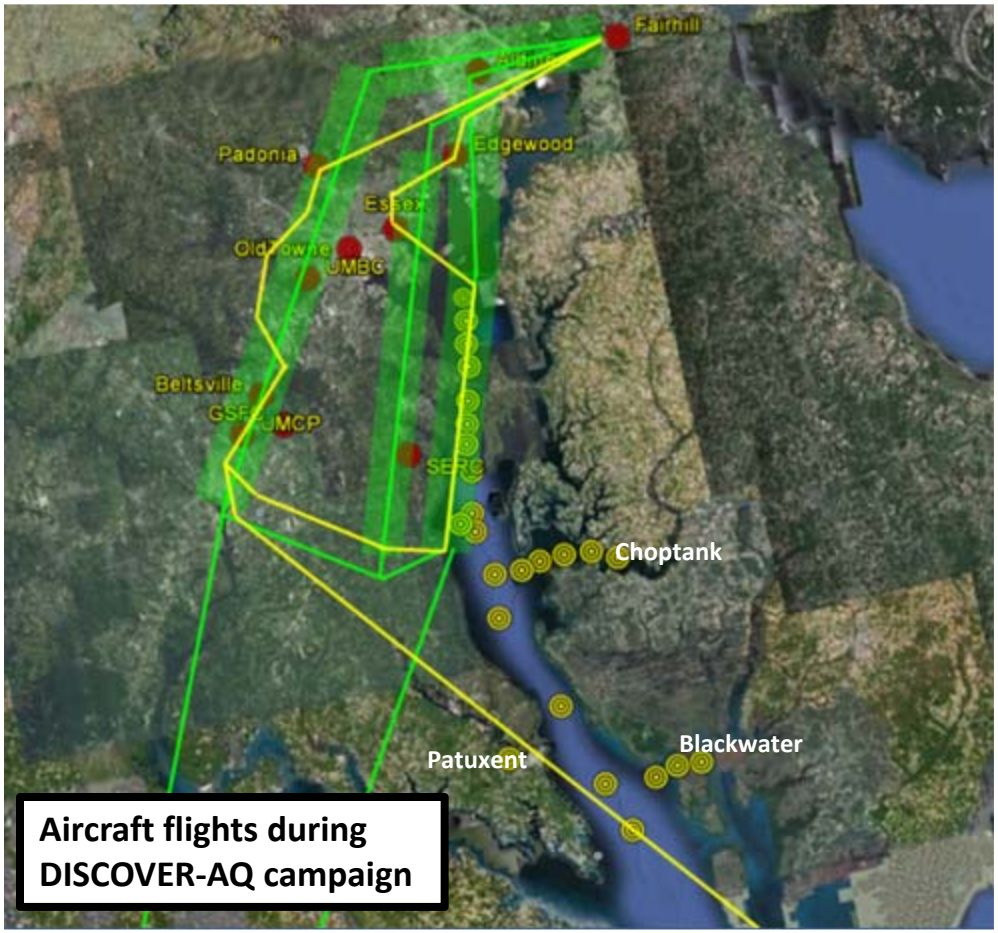
GEO-CAPE CBODAQ Campaign in the Chesapeake Bay (11-20 July 2011)



Chesapeake Bay Campaign – July 2011

Sampling: 10 cruises over a 12-day period (match with flights when possible)

Spatial:	•2 days: stationary - measurements at one location - upper bay main stem **(1 flight day)** •3 days: follow water mass (drifter w/ GPS tracking) - upper bay main stem **(2 flight days)** - lower Patuxent river •5 days: transects - 2 transects in upper bay **(2 flight days)** - 1 transect in mid bay - Choptank River/estuary - Blackwater Wildlife Refuge marshes
Temporal:	6 to 10 discrete stations during each day
Vertical:	3 depths (surface, 10% and 1% light depth)



Aircraft flights during DISCOVER-AQ campaign

July 11 - T1 transect (DISCOVER AQ flights)
July 12 - Stationary diurnal sampling at T2-1 station
July 13 - T4 transect in Choptank River/estuary
July 14 - D1 drifter in upper bay (DISCOVER AQ flights)
July 15 - D2 drifter in lower Patuxent River
Micro-pulse Lidar installed on the evening of July 15th
July 16 - T5 transect (DISCOVER AQ flights)
July 17 - T2 transect
July 18 - Drifter at T2-2 station (Russ Dickerson/UMD overflight)
July 19 - T3 transect in Blackwater Wildlife Refuge marshes
July 20 - Stationary diurnal sampling at S3 station (DISCOVER AQ flights)

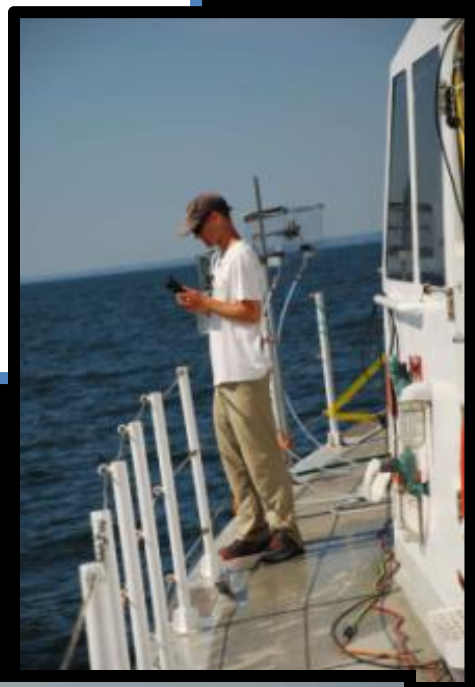
GEO-CAPE CBODAQ Campaign in the Chesapeake Bay (11-20 July 2011)

GEO-CAPE CBODAQ Campaign in the Chesapeake Bay (11-20 July 2011)

GEO-CAPE CBODAQ Campaign in the Chesapeake Bay (11-20 July 2011)

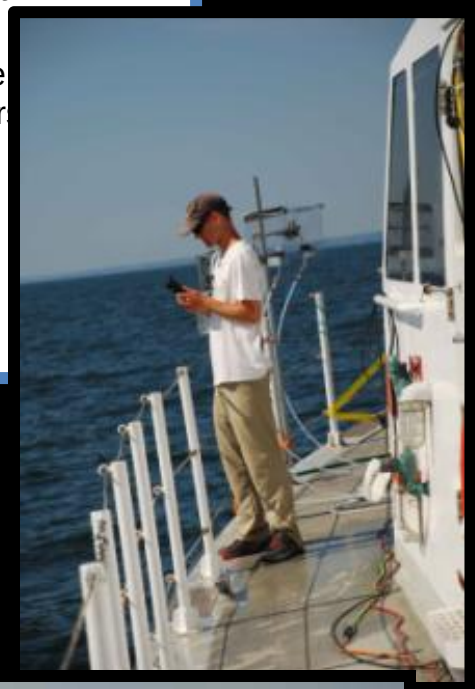
Objectives of oceanographic campaign:

- Study small scale and short-term dynamics in biogeochemical variables
- De-convolve spatial gradients with diurnal variability
- Examine and understand the causes of diurnal variability including tides, in situ production or transformations, river discharge, etc.
- Study dissipation/dispersion of phytoplankton communities, sediments, POM, DOM, and contaminants (incl. episodic events in rivers, estuaries and lakes).
- Look at diurnal phytoplankton physiological dynamics & implications for NPP models
- Algorithm development for coastal ocean products



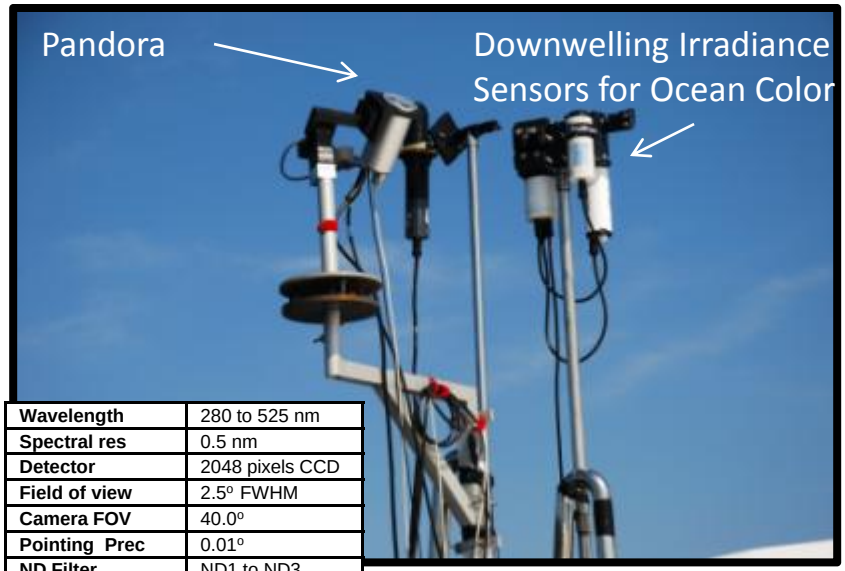
Objectives of oceanographic campaign:

- Coordinate with aircraft measurements and apply DISCOVER AQ airborne and ship-based measurements of aerosols and trace gases (ozone, NO2, etc.) to evaluate the spatial and temporal variability of these atmospheric constituents and what this variability represents in terms of uncertainties in GEO-CAPE ocean color data products (e.g. Rrs, chlorophyll-a, etc.) based on current measurement and instrument requirements.
- Process ACAM airborne data for ocean color applications (apply sensor calibrations, reflectance measurements and atmospheric data to retrieve nLw in UV-NIR); Validation of ACAM nLw (or Rrs using in situ nLw (or Rrs) computations.
- Apply results from ocean and air-quality measurements to examine **optical closure** in the ocean-atmosphere system using radiative transfer
- Calculation of fluxes to assess the role of the upper Chesapeake as a net source/sink for certain aerosols and trace gases.

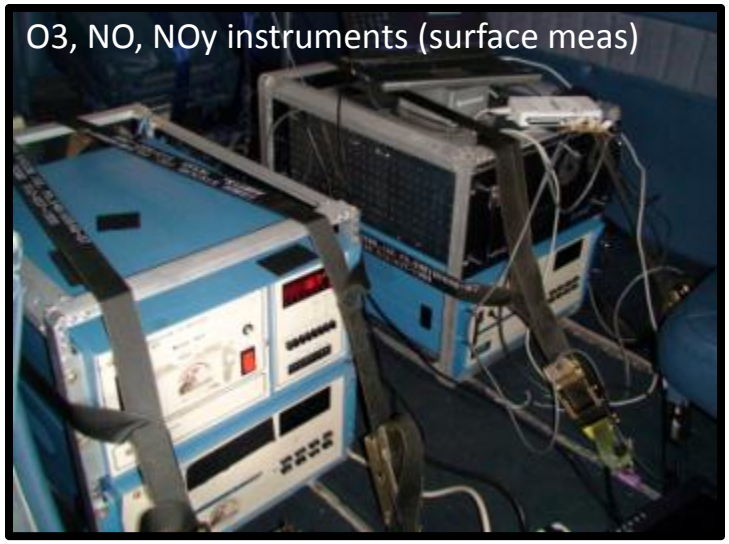


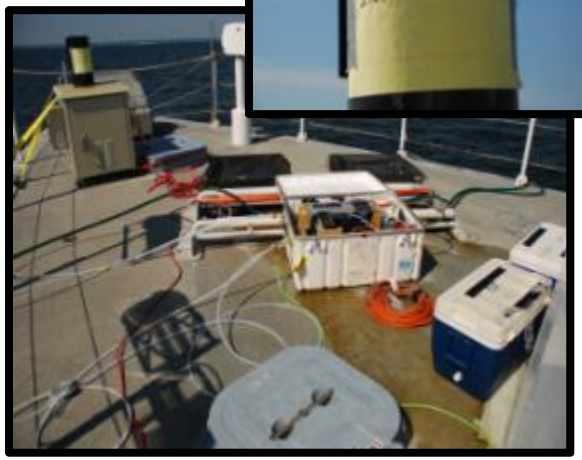
Measured Parameters
Water Inherent Optical Properties (IOPs): Total in-water absorption, a, scattering, b, attenuation, c, backscattering, bb, (ac-9, ac-s, VSF3, ECO triplet, CTD) – surface measurements and in-water profiles **More Optical Parameters:** Fluorometric Chlorophyll-a Chl-a, phytoplankton absorption spectra, aph, non-algal particulate absorption spectra, ad, colored dissolved organic matter absorption spectra, aCDOM, CDOM fluorescence Excitation Emission Matrices, EEMs
Radiometry: Surface Down-welling Irradiance, Es, Upwelling Radiance, Lu, Down-welling Irradiance, Ed, Water-leaving radiance, Lw, Remote Sensing Reflectance, Rrs, Normalized water leaving radiance, nLw, exact nLw, Q, Fo, %LL, Photosynthetically active radiation, PAR, Diffuse attenuation coefficient, Kd, KdPAR, KLu, Zeu, Kbio, OCnVn, etc. (C-Ops; 19-band UV-NIR sensor; 10nm FWHM) – profiles Ed, Lu, Es - HyperPro (UV-NIR; 3nm FWHM). NIR hand-held above-water radiometer/ 350 to 880 nm 512 channels (15 days).
Biogeochemical variables: Particulate Organic carbon and nitrogen, POC/PN, Dissolved Organic Carbon DOC, Total Dissolved Nitrogen, TDN, Suspended Particulate Matter, SPM; HPLC pigments (no cost); Phytoplankton cell count sample collection;
Primary Productivity incubations
Phytoplankton cell counts
O2 and partial pressure CO2 pCO2, Dissolved Inorganic Carbon DIC, Total Alkalinity TA, pH
Measurements of aerosols/trace gases: **AOD –** Microtops instruments **Total Column NO_2, O_3, SO_2, H_2O, HCHO, BrO -** Pandora measurements **Surface O_3, NO, NOy –** In-situ sensors on the ship **Boundary Layer Height and NRB –** Micropulse Lidar (MPL) measurements **Aerosols and Trace Gases -** Samples of CH4 Analysis for water-soluble inorganic ions; Organic analysis; Detailed information on submicron size distributions. Targeting diurnal variability; Calculation of fluxes to assess the role of the upper Chesapeake as a net source/sink for these compounds as well as their diurnal variability.

Instruments for measurements of atmospheric variability

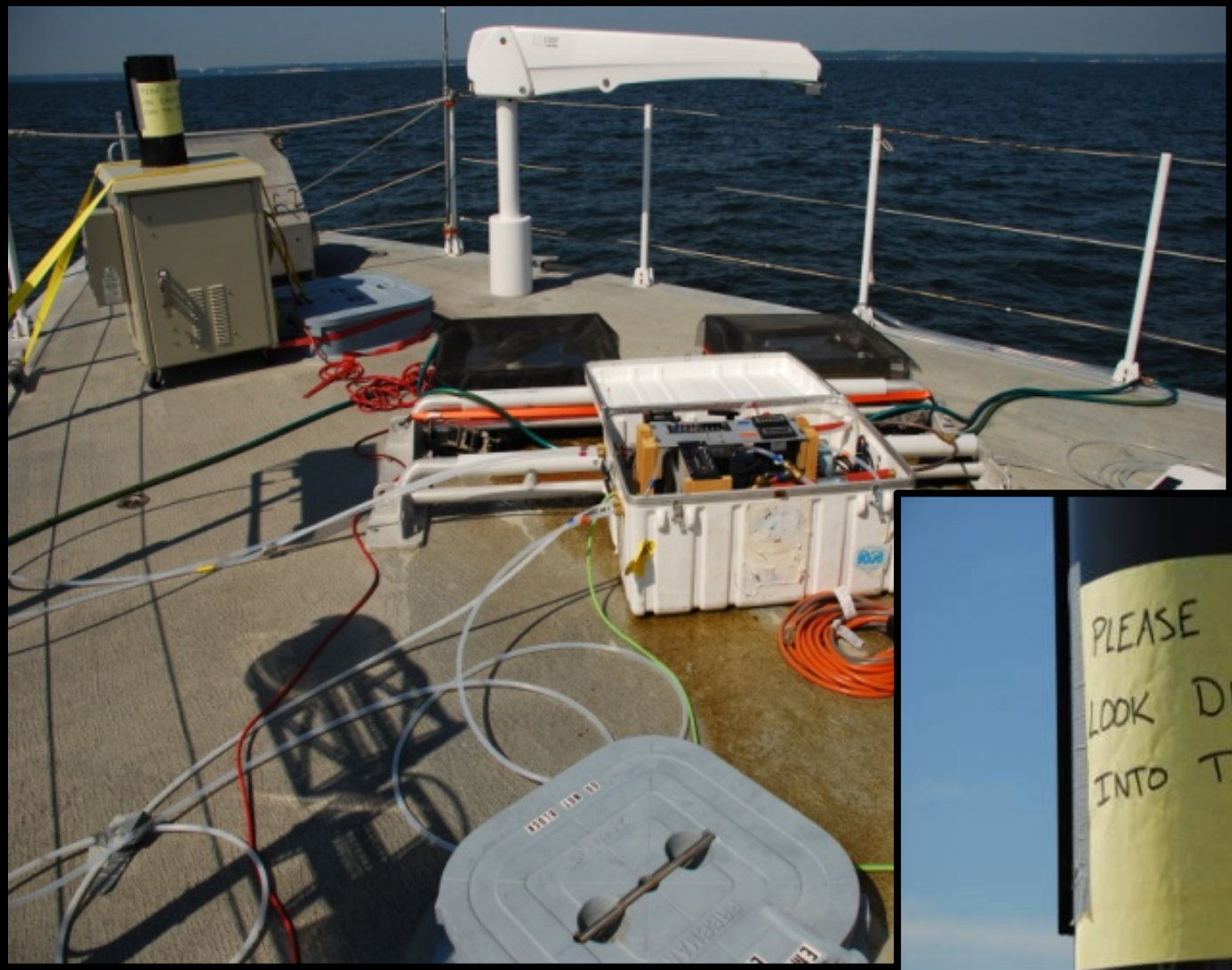


Wavelength	280 to 525 nm
Spectral res	0.5 nm
Detector	2048 pixels CCD
Field of view	2.5º FWHM
Camera FOV	40.0º
Pointing Prec	0.01º
ND Filter	ND1 to ND3

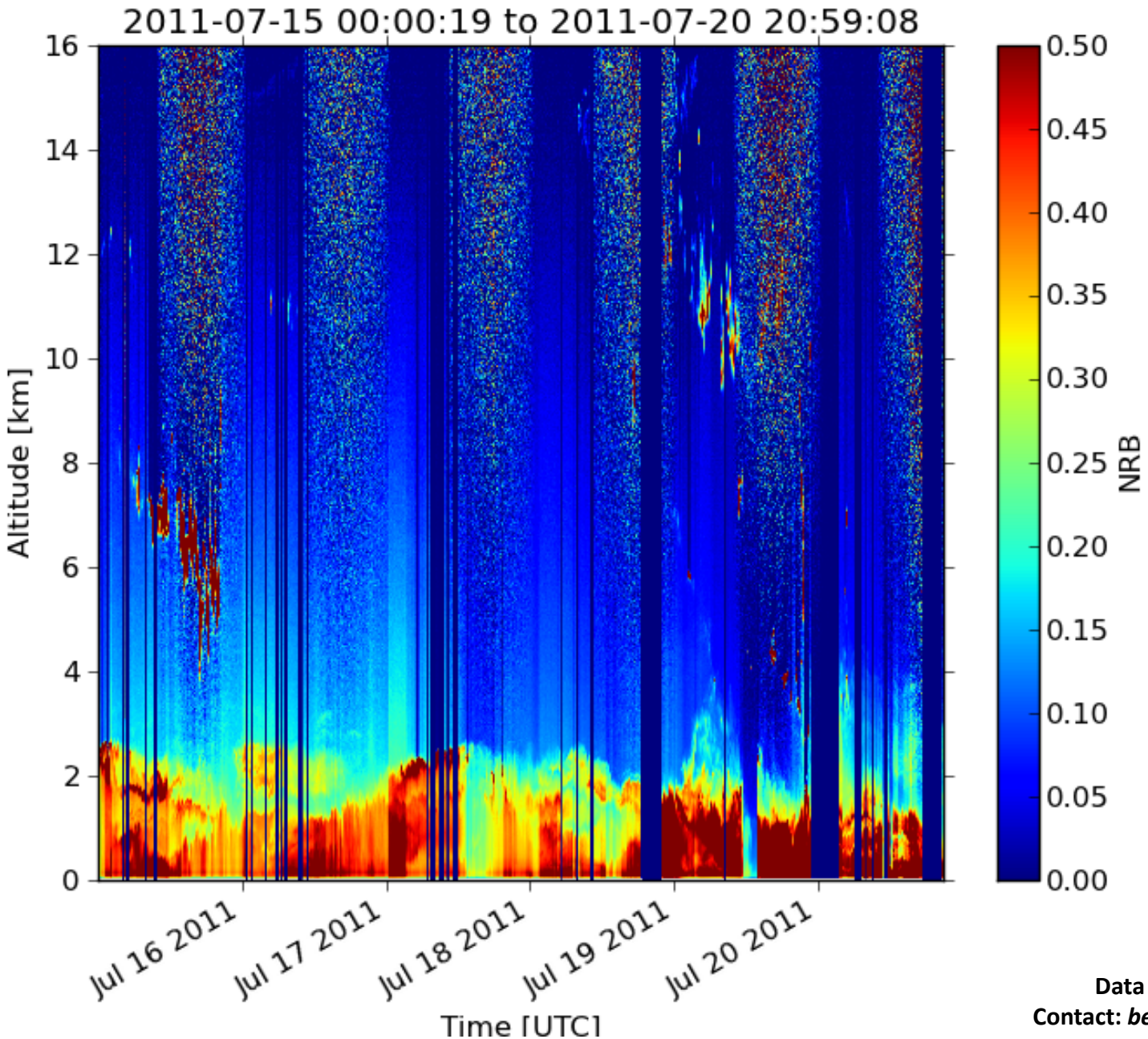




MicroPulse Lidar (MPL)
PI: Tim Berkoff



MicroPulse Lidar on the NOAA ship



Data from Tim Berkoff
Contact: ***berkoff@umbc.edu***

Filters for Aerosol Collection
PI: Carolyn Jordan

- Preliminary analysis for quality control purposes ☑
- Analysis/interpretation of measurements – on-going

Parameters measured

Bulk Aerosols:
-water-soluble inorganic ions: Cl-, NO3-, SO4=, C2O4=, Na+, NH4+, K+, Ca++
-OC/EC (Organic Carbon, Elemental Carboon), although EC was negligible during the cruise

Paired CH4 samples: atmospheric and surface seawater

Target diurnal variability and calculate fluxes

Table: Blank Corrected Means, Standard Deviations, Medians, and Range Observed in parts per trillion by volume.

		Cl^-	NO_3^-	$SO_4^=$	$C_2O_4^=$	Na^+	NH_4^+	K^+	Ca^{2+}
Chesapeake Bay Cruise 2011	Mean ± St. Dev.	583 ± 674	60 ± 64	140 ± 144	7.8 ± 7.4	512 ± 514	259 ± 259	18 ± 14	21 ± 12
	Range	34 - 3292	3 - 323	21 - 499	0.6 - 27.1	58 - 2516	48 - 909	6-58	3-51
	Median	330	45	95	4.9	379	172	12	19
Gulf of Maine 1994-1997, Marine Group	Mean ± St. Dev.	2197 ± 2181	288 ± 281	386 ± 336		1904 ± 1635	383 ± 299	44 ± 27	56 ± 44
	Range	172 - 13,952	21 - 1373	34 - 1943		187 - 10,052	59 - 1252	4 - 154	2 - 307
	Median	1398	179	286		1491	272	41	49
Gulf of Maine 1994-1997, Polluted Group	Mean ± St. Dev.	160 ± 167	282 ± 273	1803 ± 1848		484 ± 412	1935 ± 1367	50 ± 34	69 ± 42
	Range	2 - 889	8 - 1313	116 - 10,062		2 -1891	218 - 7159	6 - 179	6 - 175
	Median	99	204	1118		434	1584	45	64

Data from Carolyn Jordan
Contact: ***cej@gust.sr.unh.edu***

Aerosols Measurements using Microtops Instruments
PIs: Maria Tzortziou and Brent Holben

GODDARD SPACE FLIGHT CENTER | + Visit NASA.gov

AERONET
MARITIME AEROSOL NETWORK

+ AEROSOL OPTICAL DEPTH | + AEROSOL INVERSIONS | + SOLAR FLUX | + OCEAN COLOR | + MARITIME AEROSOL

Web Site Feature — AERONET Data Synergy Tool - Access Earth Science data sets for AERONET sites

+Home
+ AERONET Home

Maritime Aerosol

+ AEROSOL/FLUX NETWORKS
+ COLLABORATORS
+ DATA
+ NASA PROJECTS
+ PUBLICATIONS
+ STAFF
+ SYSTEM DESCRIPTION

AERONET DATA ACCESS
DATA SYNERGY TOOL
+ Data Display
AEROSOL OPTICAL DEPTH
+ Data Display
+ Download Tool
+ Download All Sites
+ Climatology Tables
+ Climatology Maps
+ V2 L2 Data Availability
AEROSOL INVERSIONS
+ Data Display
+ Download Tool
+ Download All Sites
SOLAR FLUX
+ Data Display
OCEAN COLOR

MARITIME AEROSOL NETWORK (MAN)

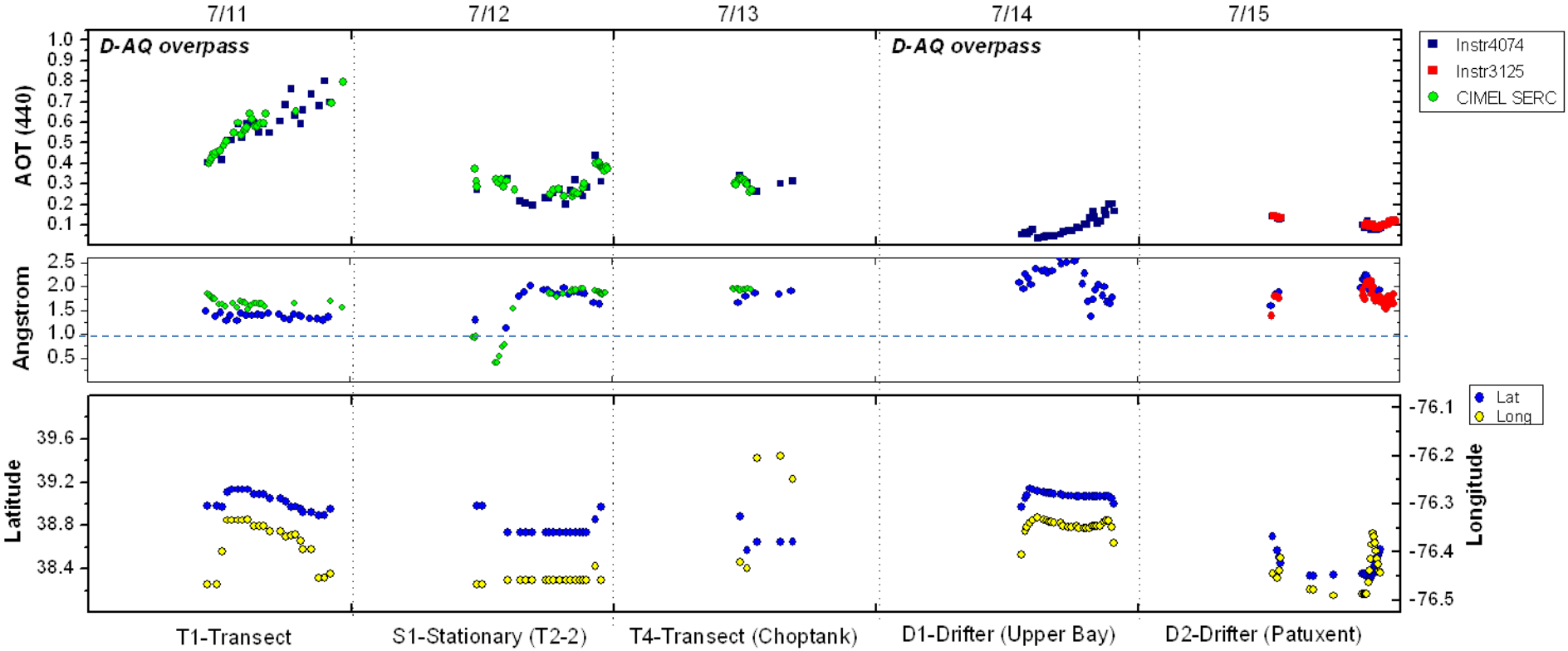
2011 SRVx 8501 Cruise

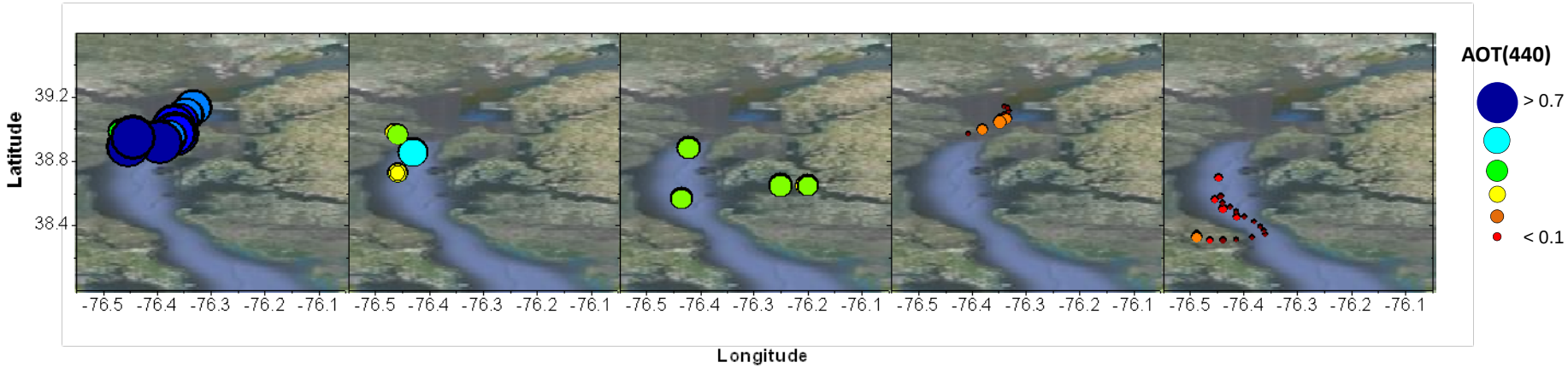
The GEO-CAPE CBODAQ (Chesapeake Bay Oceanographic campaign with DISCOVER AQ) cruise took place in Chesapeake Bay during July 2011. The goal of the cruise was to obtain field data to assist the GEO-CAPE (Tier 2 Earth Science Decadal Survey mission) science working group to further develop measurement and instrument requirements for the ocean ecosystem portion of the GEO-CAPE mission. The oceanographic field campaign coincided with the NASA DISCOVER-AQ Air Quality 2011 Summer campaign. Measurements were performed using NOAA's SRVx-8501 National Marine Sanctuary Test and Evaluation Vessel. Two-hundred fifty-nine (259) measurement series spanning six (6) days were acquired during the cruise.

Dr. Maria Tzortziou from the Earth System Science Interdisciplinary Center (ESSIC) at the University of Maryland (College Park, Maryland) was the Principal Investigator for aerosol optical depth measurements from the SRVx ship. She and members of her team, Dr. Chris Loughner, Daniel Goldberg and Vienna Saccomanno, conducted measurements onboard.

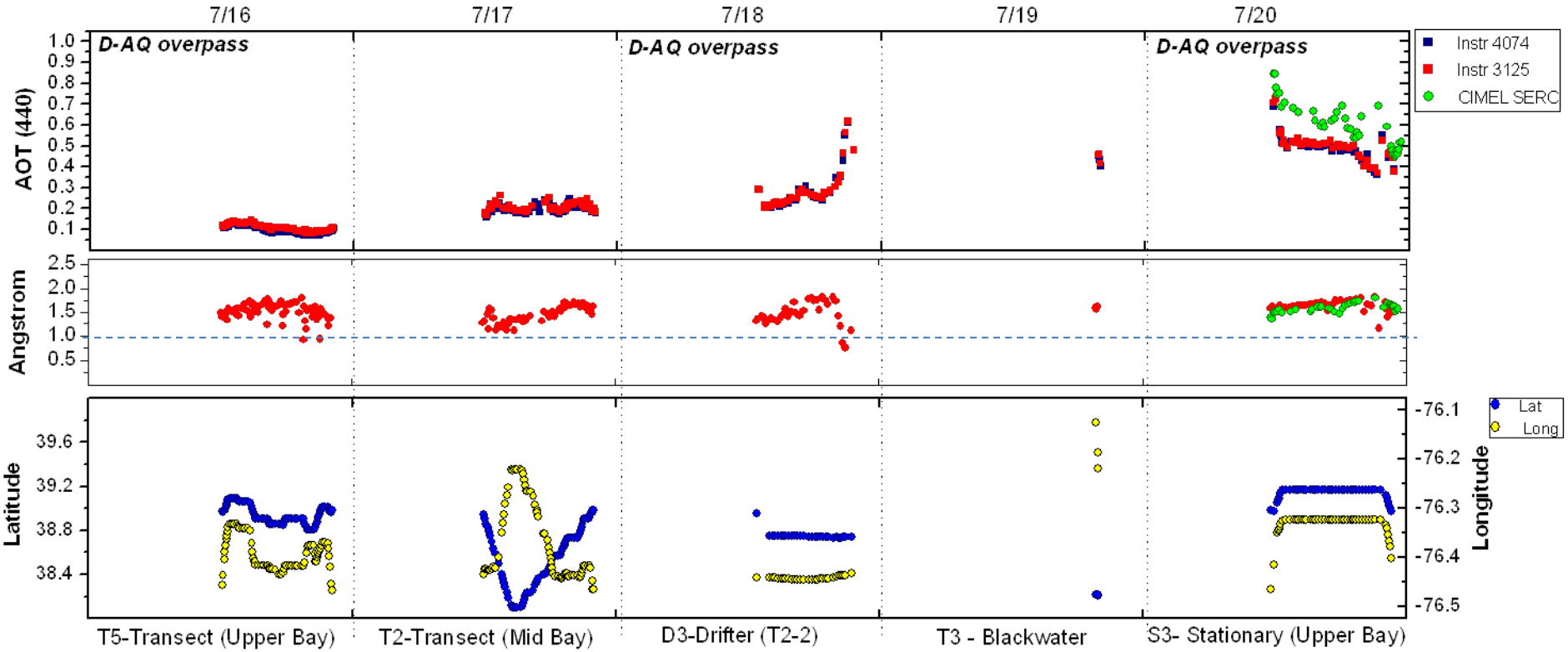
DATA

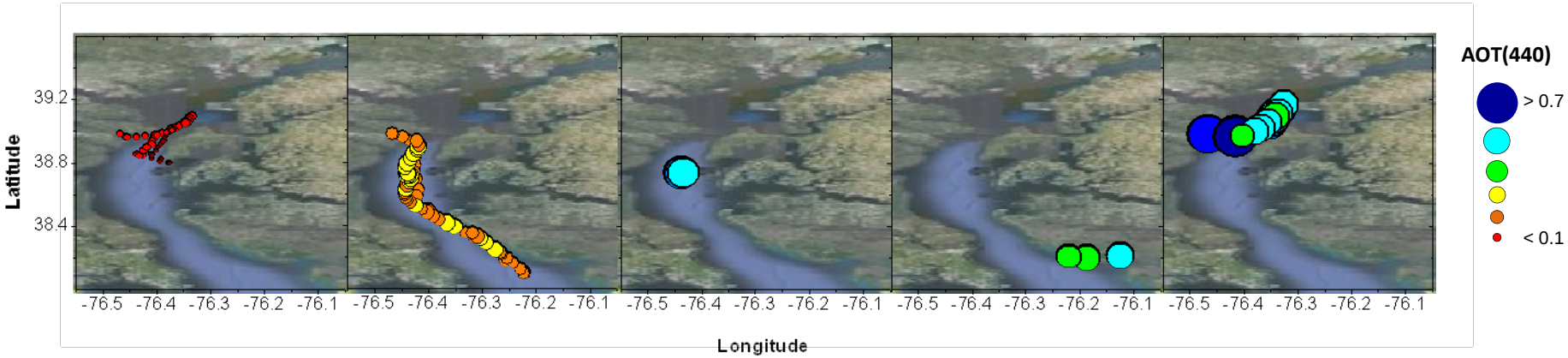
Aerosols (Microtops Sunphotometer)

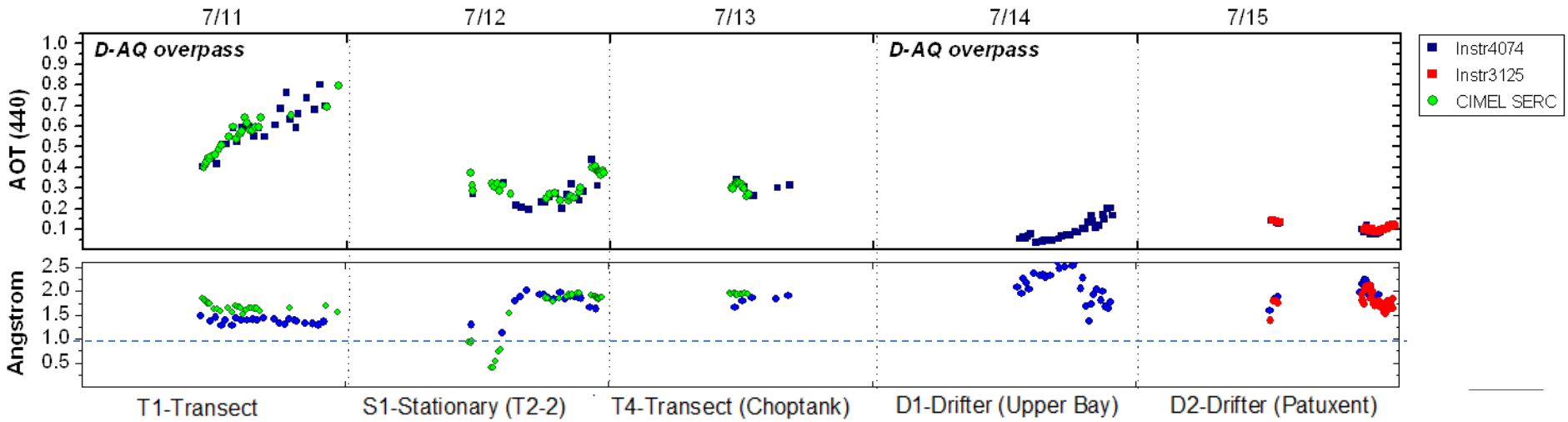




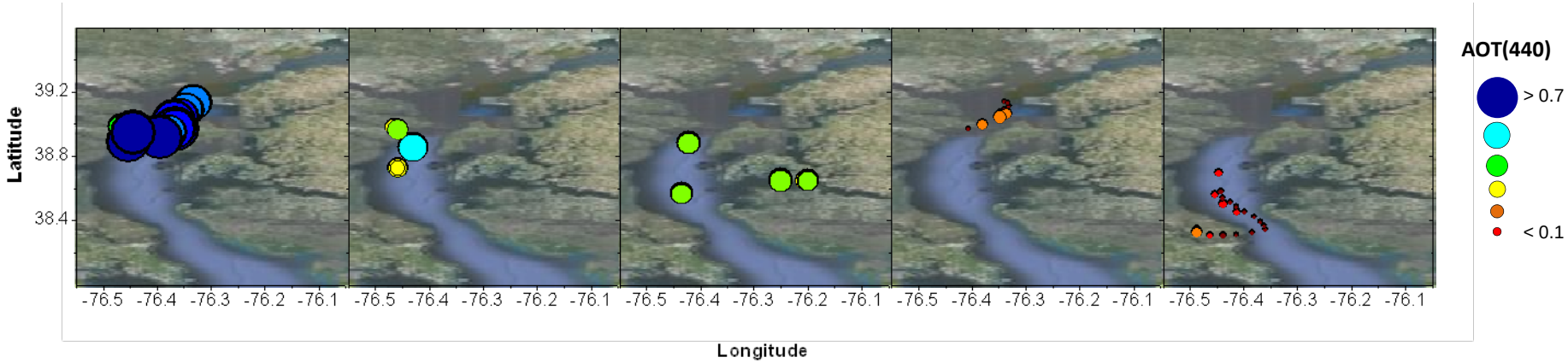
Aerosols (Microtops Sunphotometer)



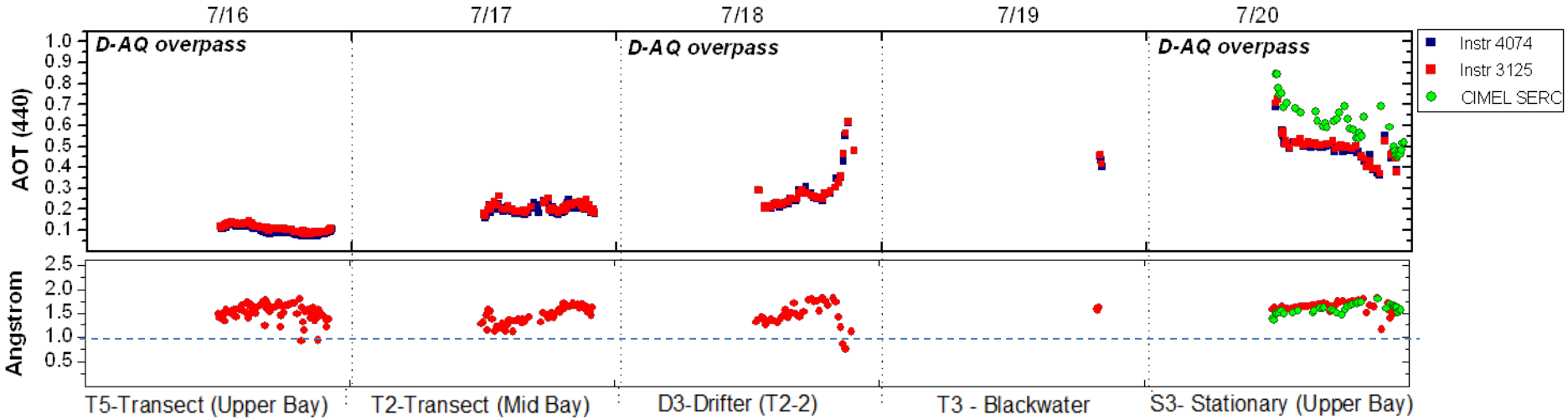




→Bad air quality days at the beginning, improving later in the week, gets worse during the last few days
→Large **variability in AOT**, by more than a factor of 2, in most days
→ Good agreement with SERC when we were close to SERC, larger differences as we move further away (AOT lower over the water)
→The **Angstrom exponent was highly variable**, but always > 1.0, showing the large influence of urban aerosols over the Bay



Aerosols (Microtops Sunphotometer)



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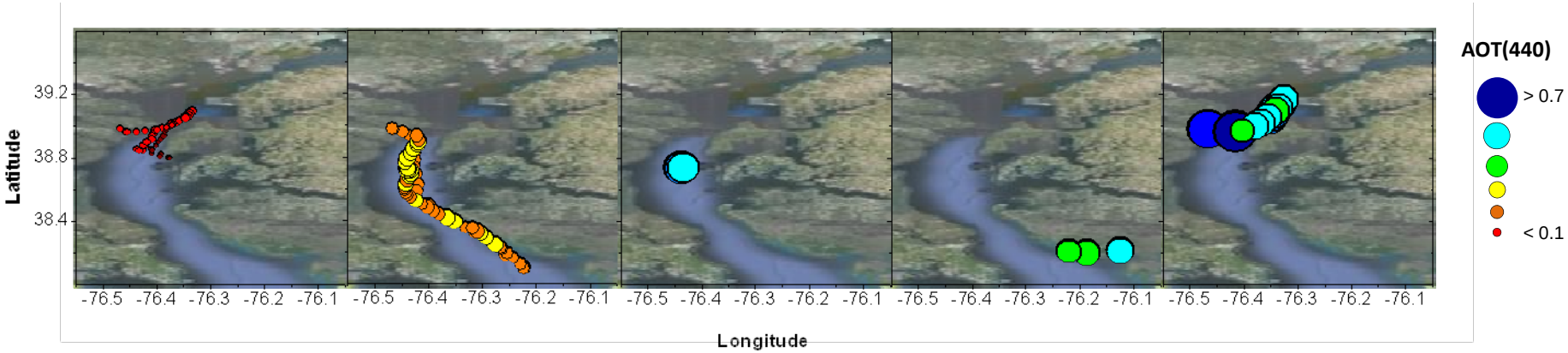
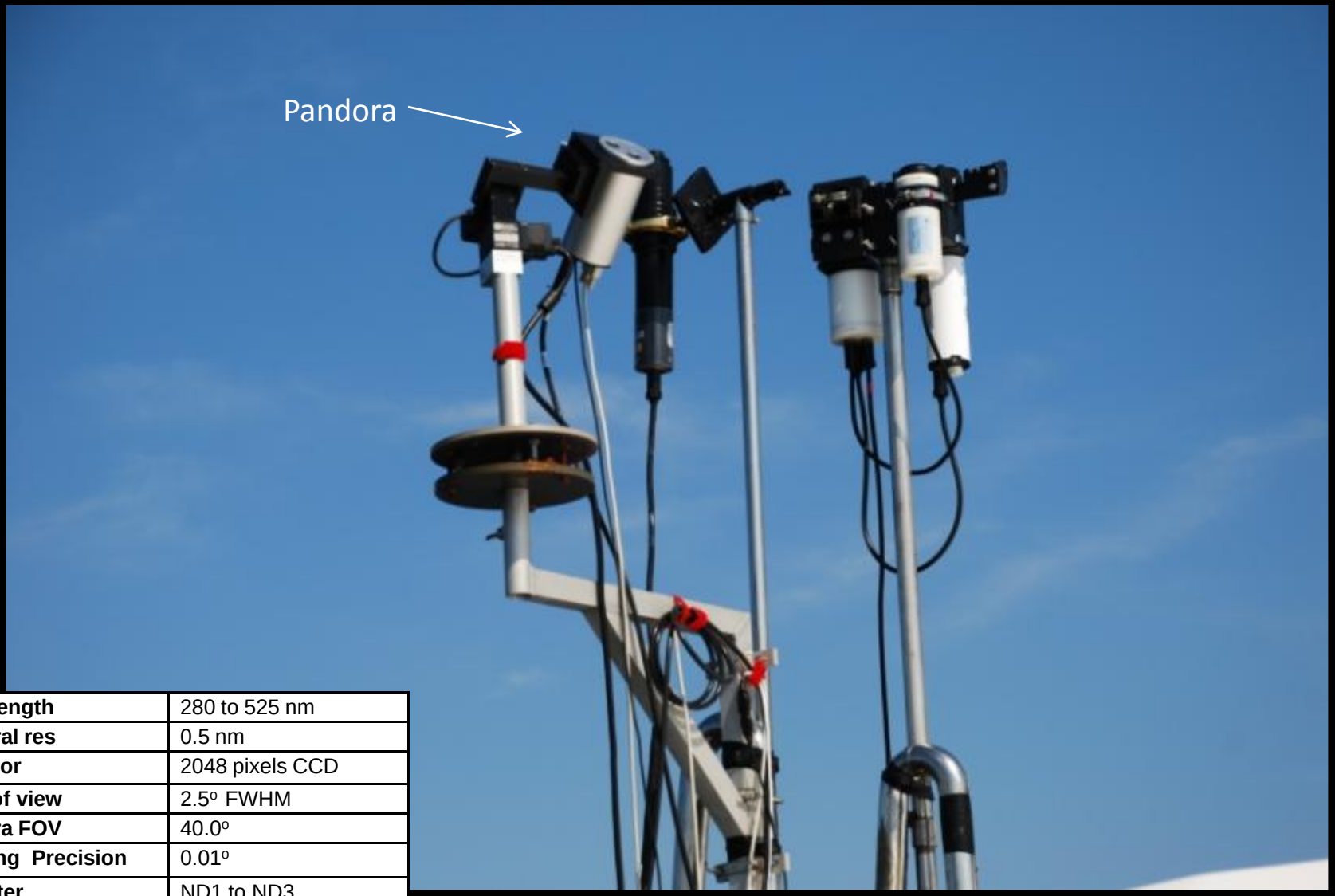


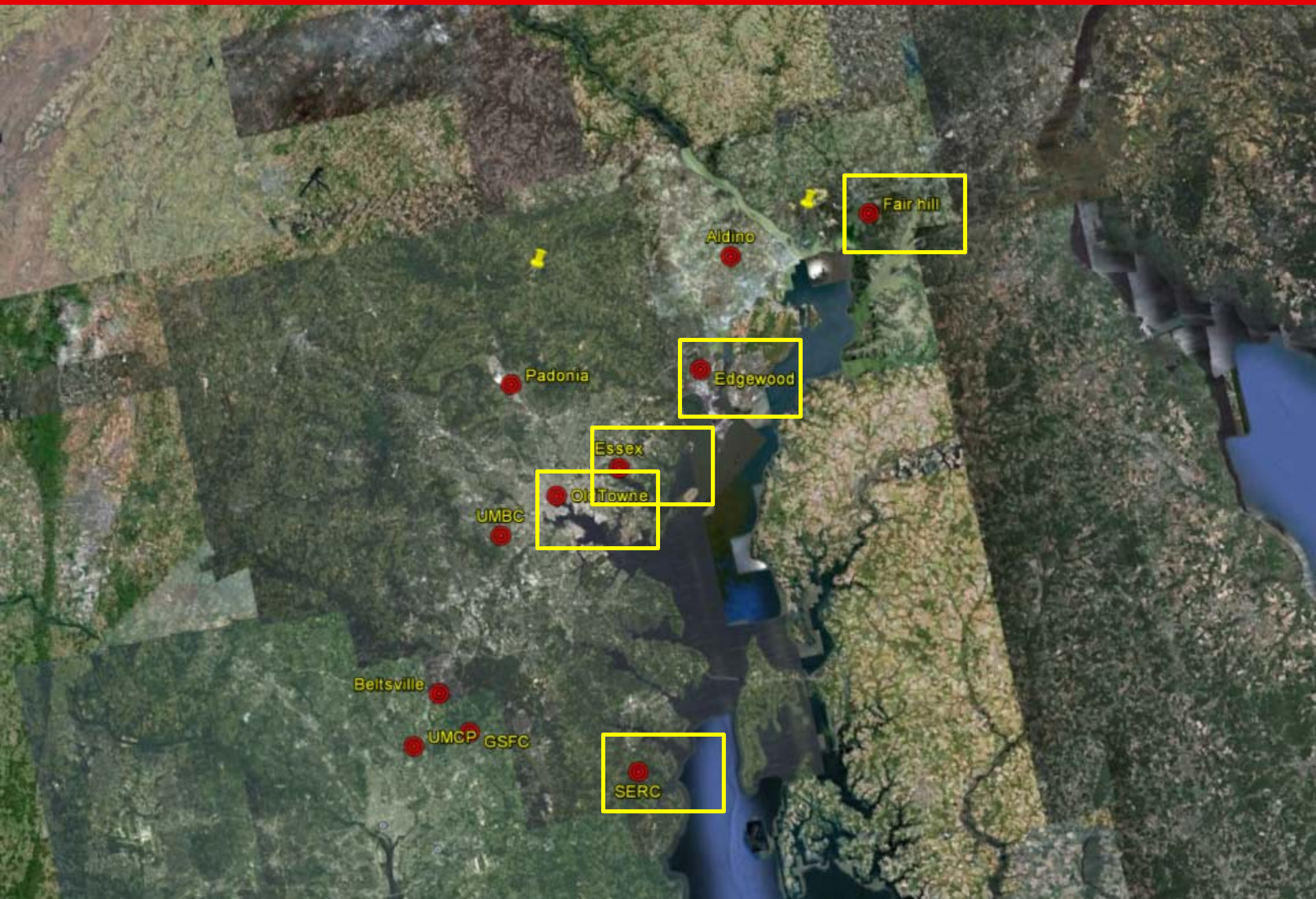
Trace Gas Measurements using the Pandora spectrometers

PIs: Maria Tzortziou and Jay Herman

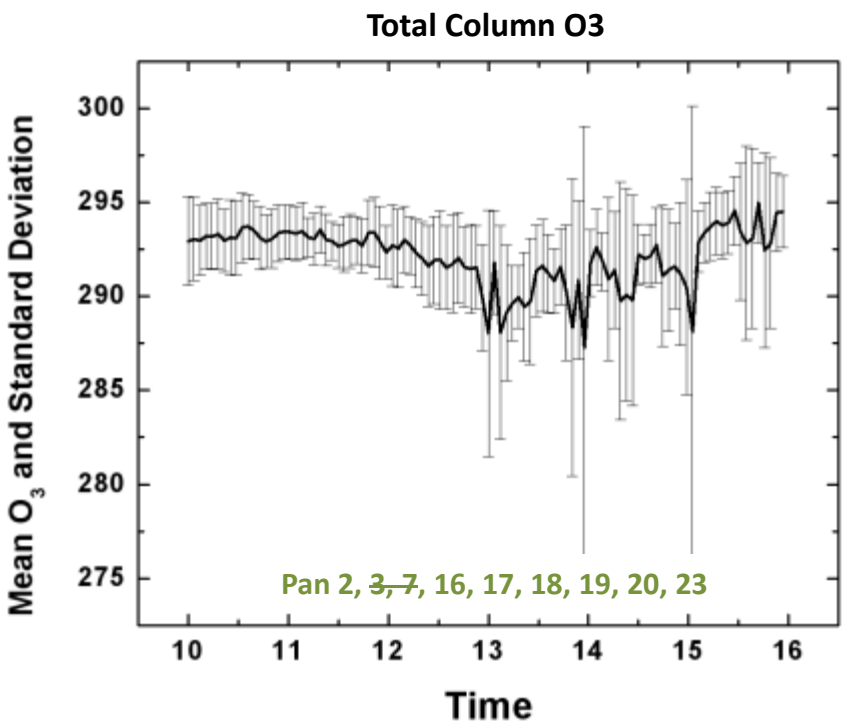


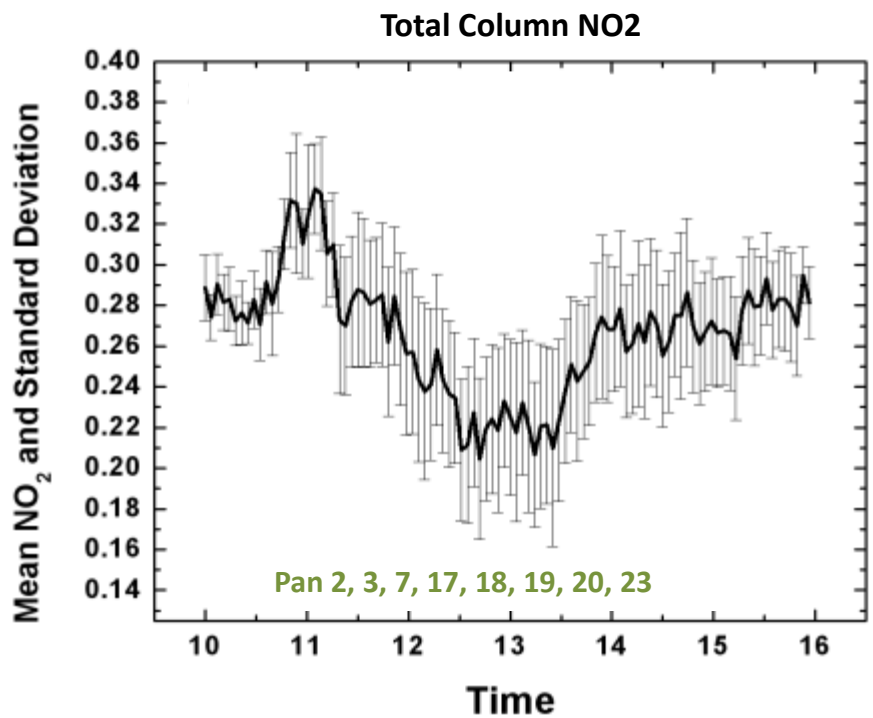
Wavelength	280 to 525 nm
Spectral res	0.5 nm
Detector	2048 pixels CCD
Field of view	2.5º FWHM
Camera FOV	40.0º
Pointing Precision	0.01º
ND Filter	ND1 to ND3

Column NO2 and O3 from the Pandora spectrometers



Pandora Instrument Intercomparison at Goddard (24 November 2011, clear day)





→ Good overall agreement between the Pandora instruments during intercomparison at Goddard.

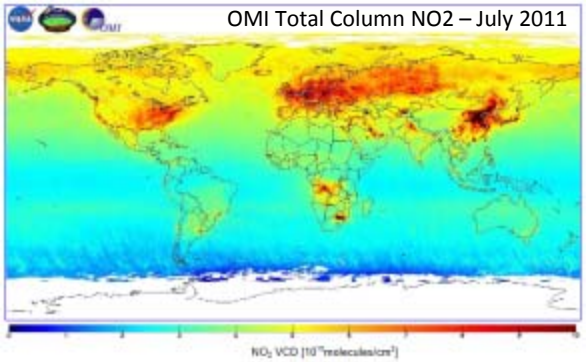
→ Pan-3 (GSFC) and Pan-7 (SERC) underestimated TCO by 5-10 DU (or approx. 2-3 %)

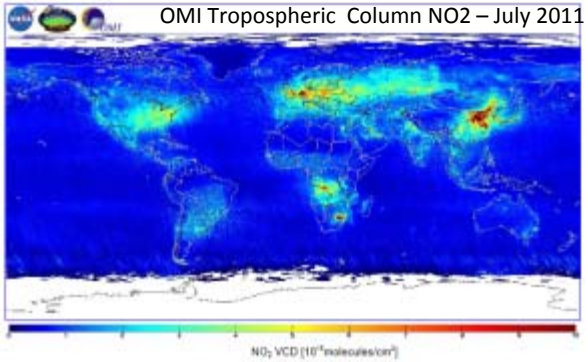
However, NO2 from Pan-3 and Pan-7 was in good agreement with the other Pandora instruments

→ Mean Standard Deviation for TCO3 = 2 DU (or approx. 0.7%)

→ Mean Standard Deviation for TCNO2 = 0.03 DU

Ozone and NO2 measurements were compared to OMI data and CMAQ simulations





Aura/OMI data

→ OMTO3 L2 OVP: TOMS like total ozone column – Station overpass
L2G: TOMS like total ozone column – Gridded dataset

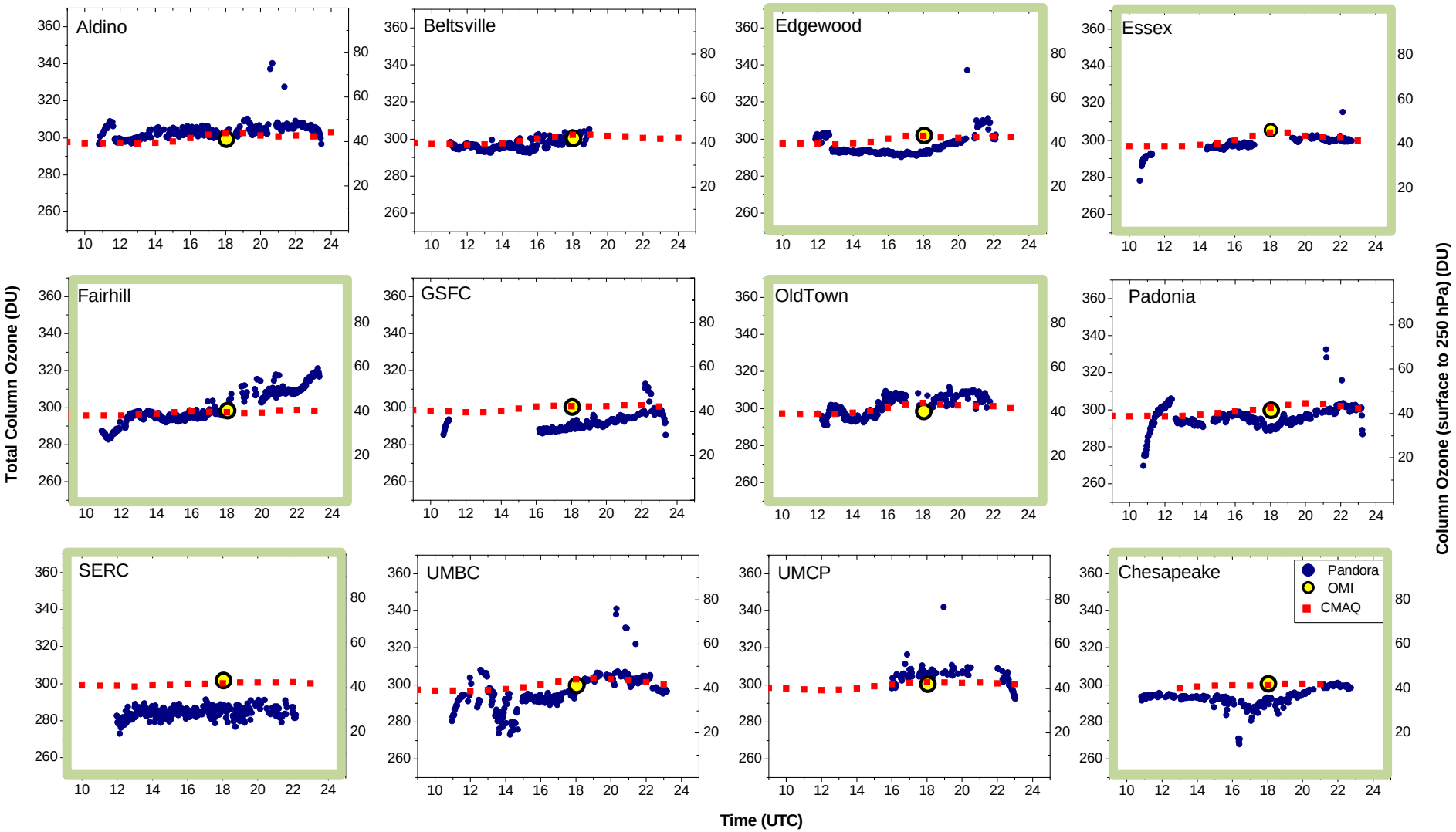
→ OMNO2 L2 OVP: NO2 total columns using the DOAS technique – Station overpass
L2G: NO2 total columns using the DOAS technique – Gridded dataset

Model Simulations

→ NOAA experimental Weather Research and Forecasting Model-
- Nonhydrostatic Mesoscale Model-Community Multi-scale Air Quality model (WRF-NMM-CMAQ) simulations **(12 km resolution)**
→ Radiation: Lacis-Hansen Bulk
→ Land Surface Model: Noah LSM
→ Boundary Layer: MYJ
→ Cumulus: Betts-Miller-Janjic
→ Microphysics: Ferrier
→ Chemical Mechanism: CB05
→ Aerosols: Aero4
→ **Emissions: 2005 National Emissions Inventory (NEI)**
→ **Chemical initial and boundary conditions: Based on climatology**

Column NO2 and O3 from the Pandora spectrometers

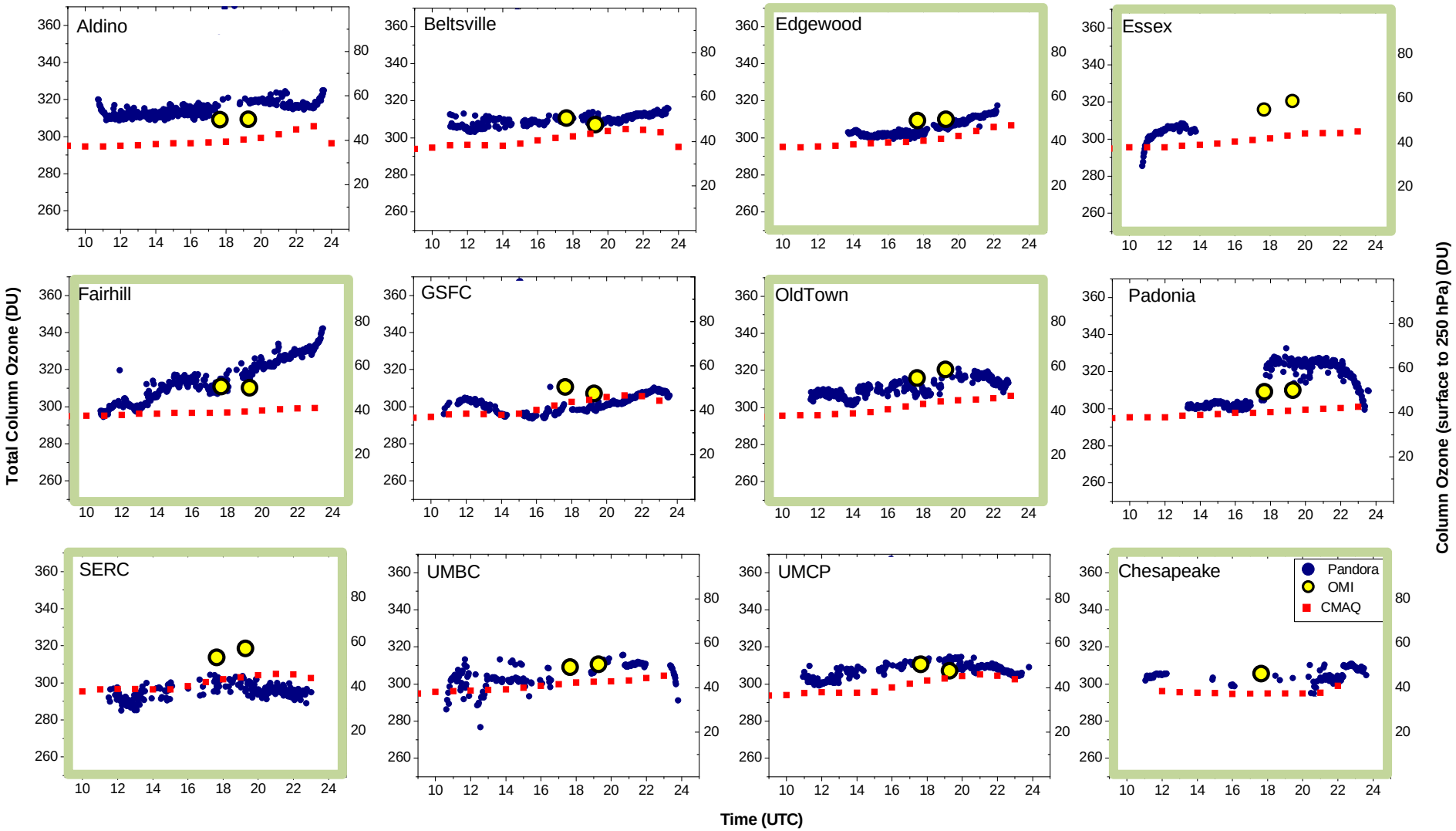
July 11, 2011 (high air pollution day)



	Aldino	Beltsville	Edgewood	Essex	Fairhill	GSFC	Old-Town	Padonia	SERC	UMBC	UMCP	Ship	Average (DU)
Pandora	302.6	299.1	293.3	301.1	301.4	291.3	301.0	290.9	288.3	299.3	306.4	292.4	
OMI	299.2	300.4	302.0	305.4	298.3	300.4	298.4	299.7	301.7	299.8	300.4	300.6	
Diff %	**1.1%**	**-0.4%**	**-2.9%**	**-1.4%**	**1.0%**	**-3.1%**	**0.9%**	**-3.0%**	**-4.5%**	**-0.2%**	**2.0%**	**-2.8%**	**- 3.3 (-1.0%)**

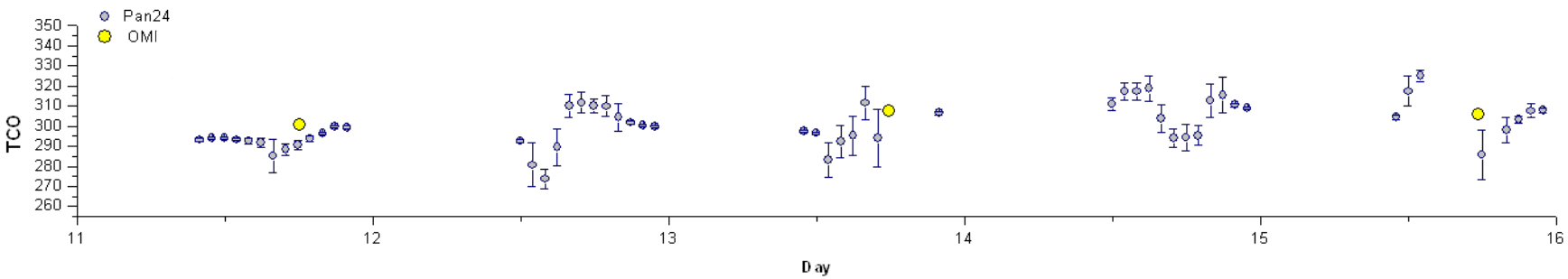
Column NO2 and O3 from the Pandora spectrometers

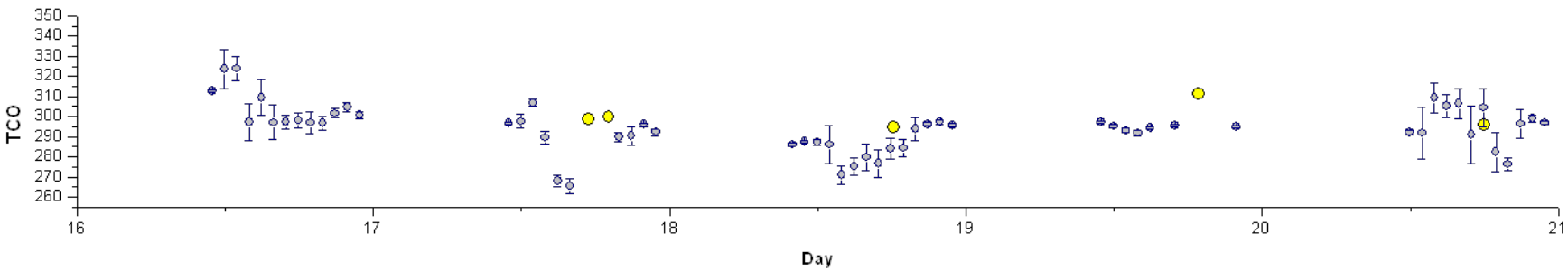
July 15, 2011 (relatively low air pollution day)



	Aldino	Beltsville	Edgewood	Essex	Fairhill	GSFC	Old-Town	Padonia	SERC	UMBC	UMCP	Ship	Average (DU)
Pandora	316.5	310.7	303.5		309.7	301.3	306.5	309.8	298.2	306.4	312.7	304.6	
OMI	309.2	310.7	309.3		310.9	310.7	315.8	309.2	313.8	309.1	310.7	305.7	
Diff %	**2.3%**	**0.0%**	**-1.9%**		**-0.4%**	**-3.1%**	**-3.0%**	**0.2%**	**-5.1%**	**-0.9%**	**0.6%**	**-0.4%**	**- 3.2 (-1.0%)**

Column NO2 and O3 from the Pandora spectrometers



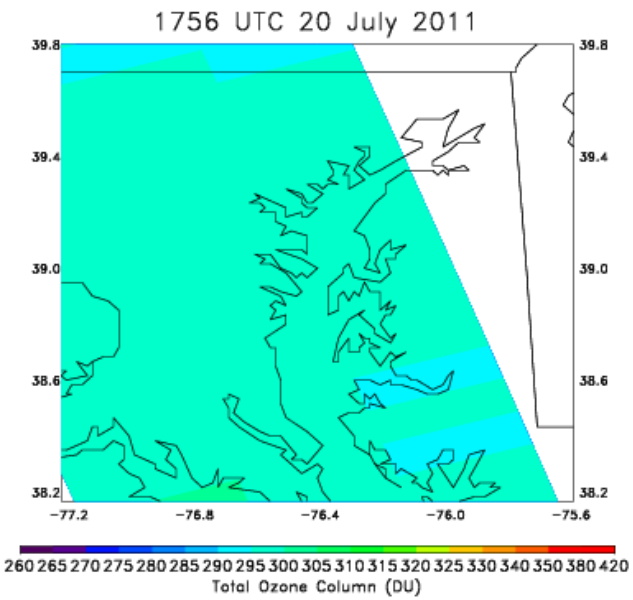


→ Some variability in TCO from Pandora on the boat
→ Overall agreement with satellite. OMI, however, consistently overestimated TCO over the water (on avg by 3.5%)

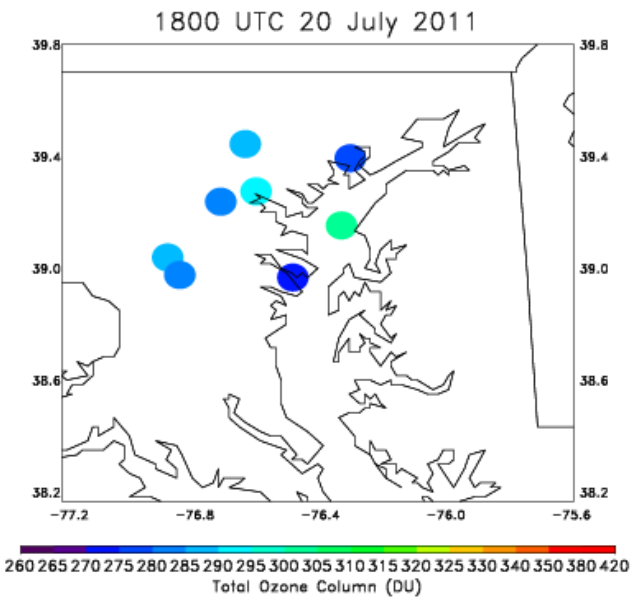
	11 July	12 July	13 July	14 July	15 July	16 July	17 July	18 July	19 July	20 July	Average (DU)
Pandora	290.56	-	294.12	-	285.73	-	289.65	284.04	295.51	304.50	
OMI	300.58	-	307.53	-	305.73	-	300.12	294.84	311.41	295.61	
Diff %	**-3.4%**	**-**	**-4.5%**	**-**	**-6.8%**	**-**	**-3.6%**	**-3.7%**	**-5.2%**	**3.0%**	**- 3.5%**

Spatial and Temporal Variability in Total Column Ozone

OMI satellite data



Pandora Ground Based



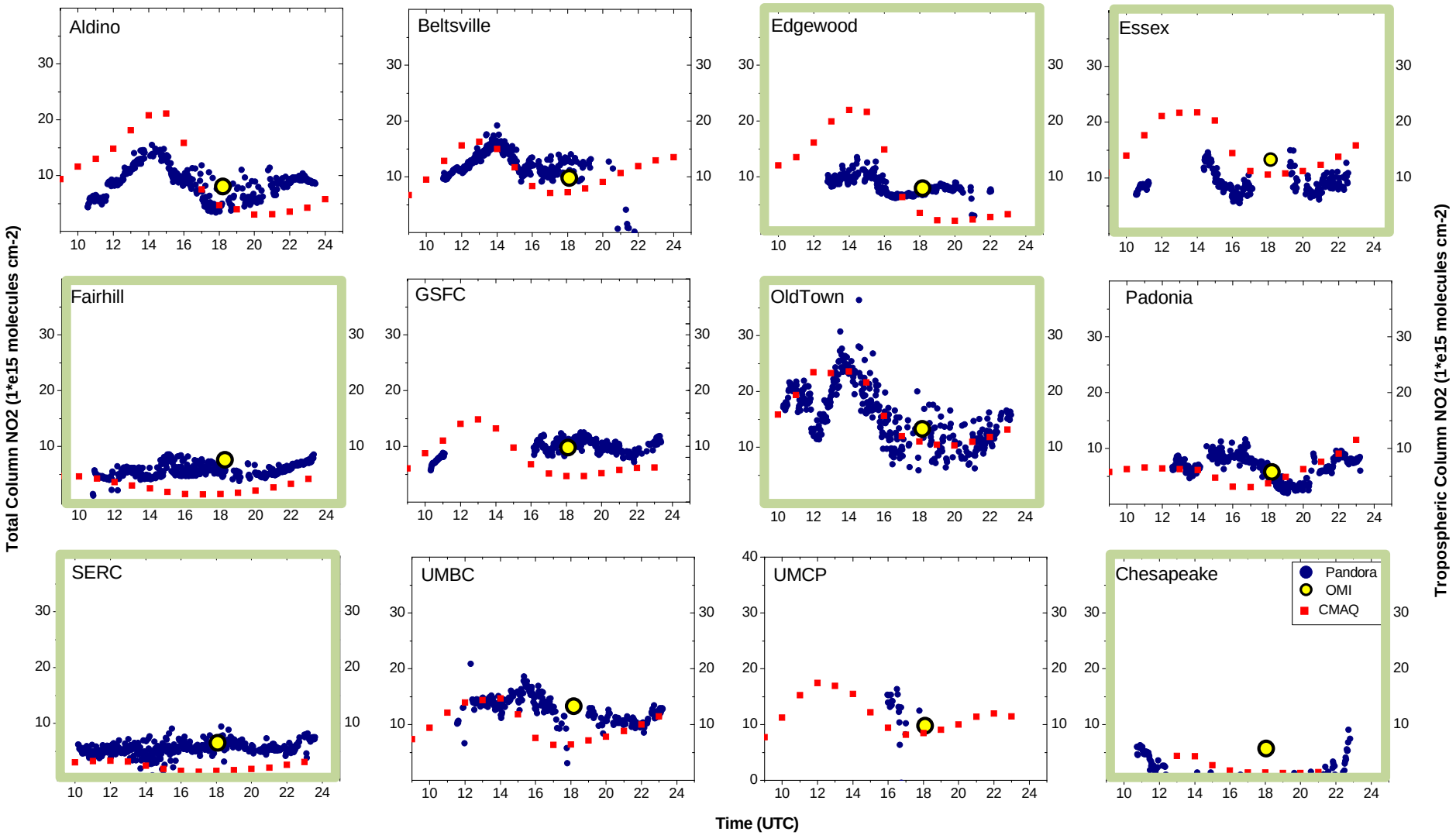
→ Overall good agreement between Pandora and OMI (when small satellite footprint)

→ As expected, when satellite footprint is large, OMI does not capture gradients shown in CMAQ and Pandora

→ OMI overestimates NO2 along the Chesapeake Bay shoreline (e.g. Pandora SERC) and over the Bay (CMAQ results)

Column NO2 and O3 from the Pandora spectrometers

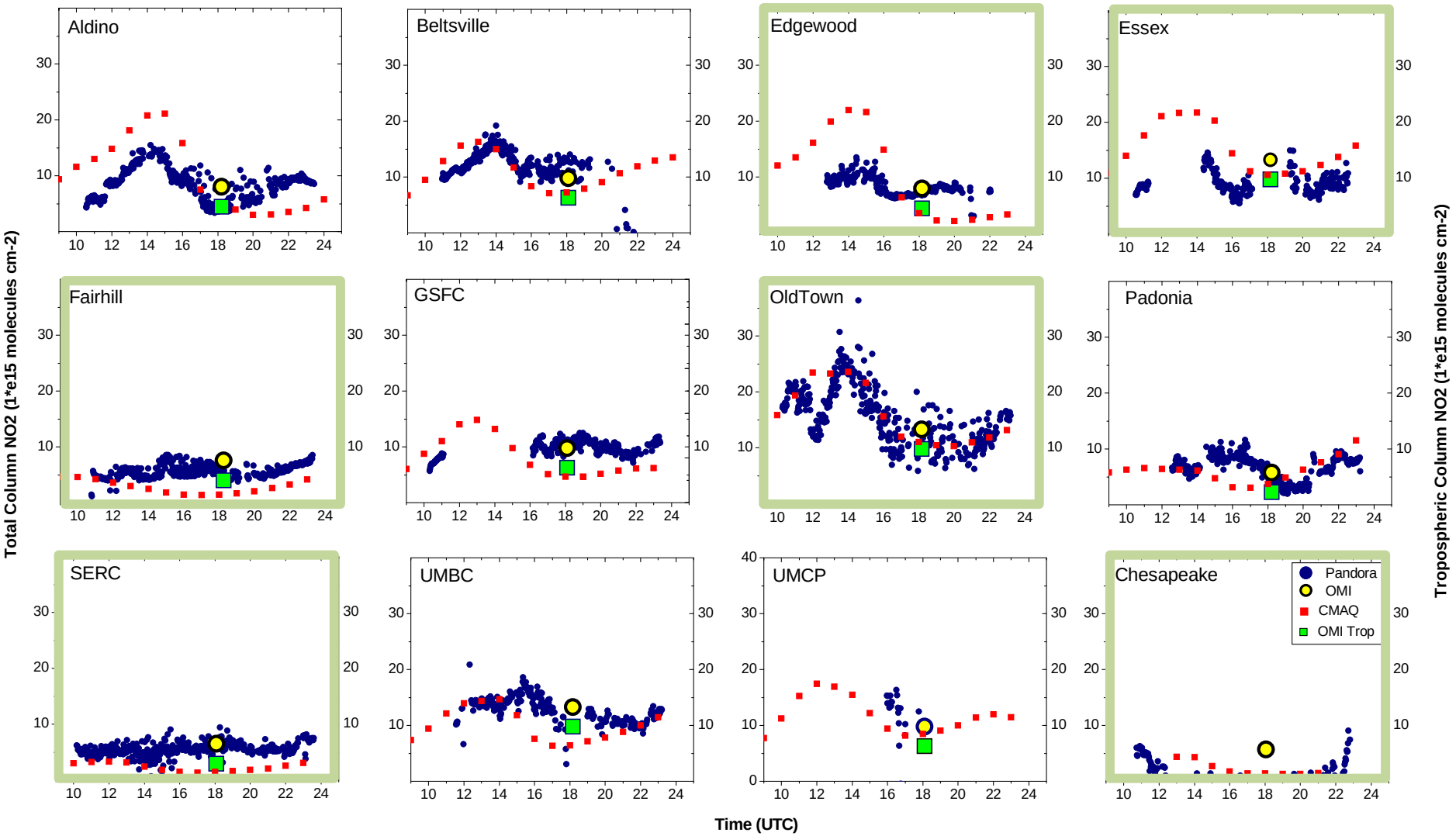
July 11, 2011



	Aldino	Beltsville	Edgewood	Essex	Fairhill	GSFC	Old-Town	Padonia	SERC	UMBC	UMCP	Ship	Avg (1*e 15 mol/cm 2)
Pandora	4.96	11.14	6.73	12.14	5.73	11.19	11.69	5.71	7.37	11.58	12.50		
OMI	8.03	9.80	7.96	13.30	7.60	9.80	13.30	5.79	6.46	13.30	9.80	5.73	
Diff %	**-12%**	**13%**	**-17%**	**-9%**	**-28%**	**13%**	**-13%**	**-1%**	**13%**	**-14%**			**- 0.66 (- 5.5%)**

Column NO2 and O3 from the Pandora spectrometers

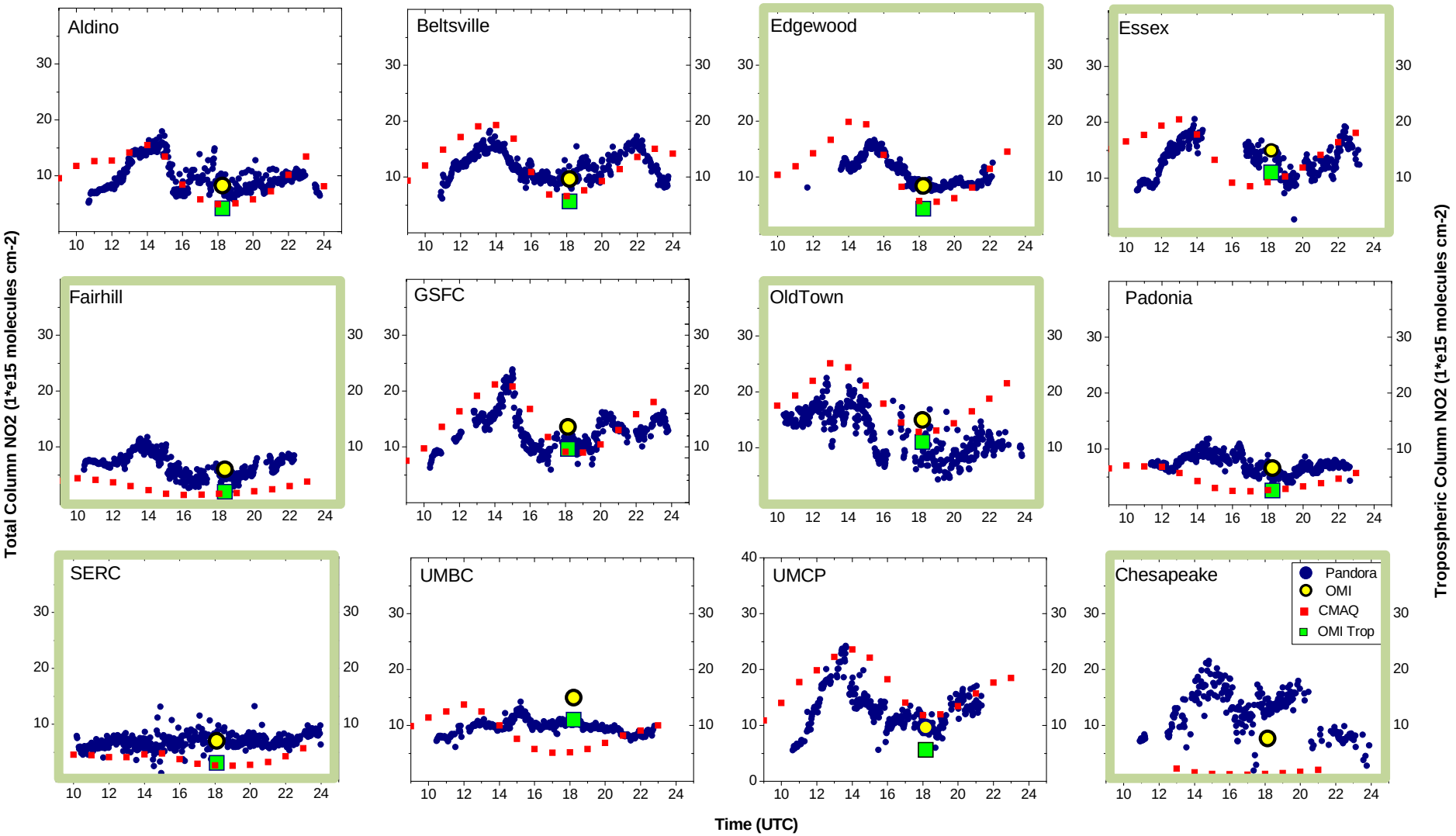
July 11, 2011



	Aldino	Beltsville	Edgewood	Essex	Fairhill	GSFC	Old-Town	Padonia	SERC	UMBC	UMCP	Ship	Avg (1*e ^{15} mol/cm ^{2})
Pandora	4.96	11.14	6.73	12.14	5.73	11.19	11.69	5.71	7.37	11.58	12.50		
OMI	8.03	9.80	7.96	13.30	7.60	9.80	13.30	5.79	6.46	13.30	9.80	5.73	
Diff %	**-12%**	**13%**	**-17%**	**-9%**	**-28%**	**13%**	**-13%**	**-1%**	**13%**	**-14%**			**- 0.66 (- 5.5%)**

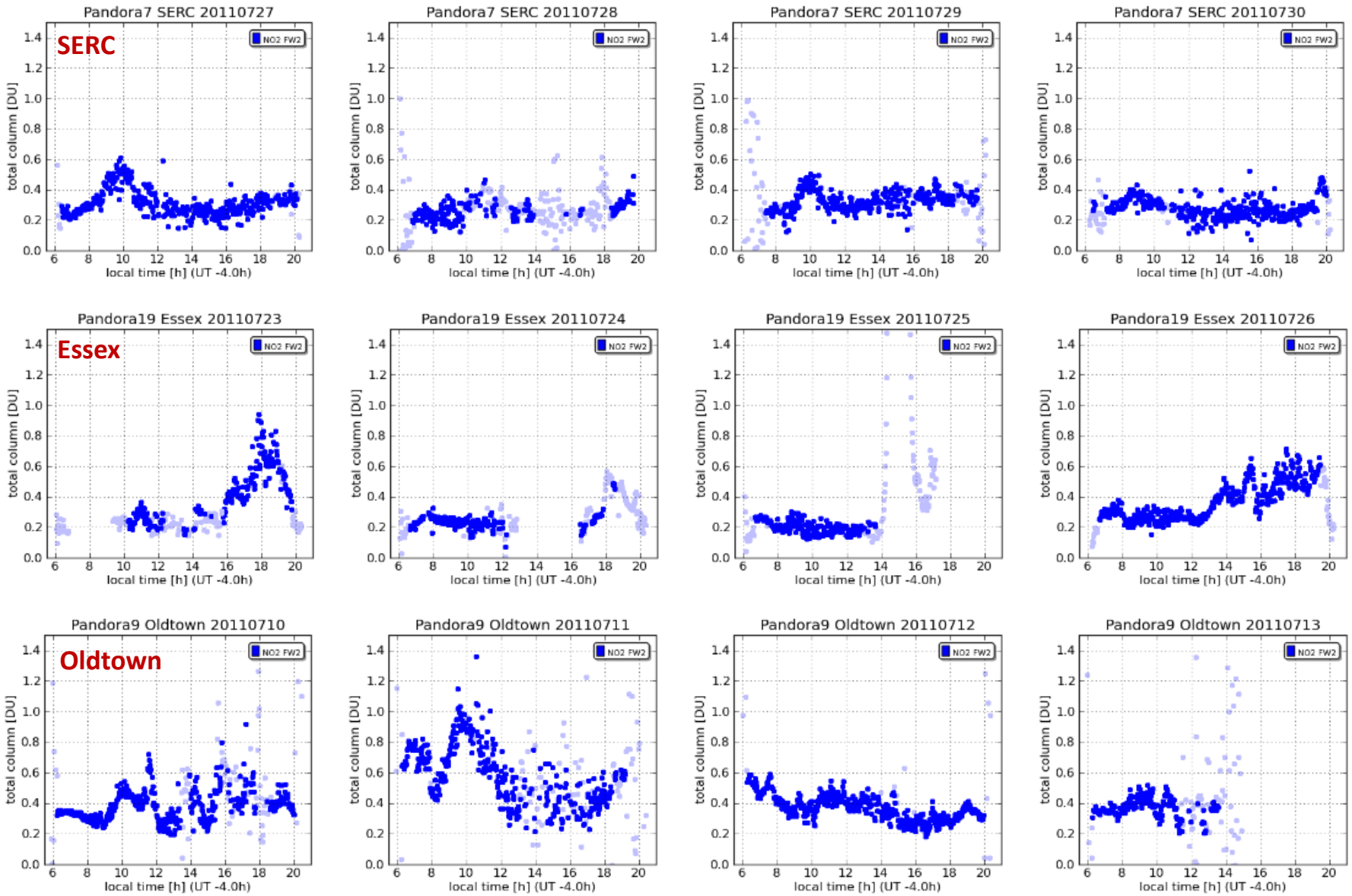
Column NO2 and O3 from the Pandora spectrometers

July 18, 2011



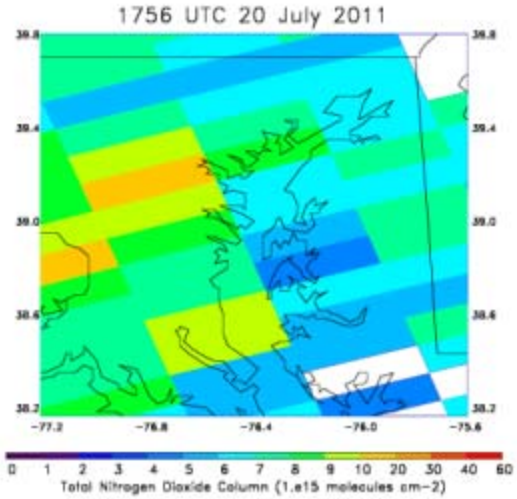
	Aldino	Beltsville	Edgewood	Essex	Fairhill	GSFC	Old-Town	Padonia	SERC	UMBC	UMCP	Ship	Avg (1*e ^{15} mol/cm ^{2})
Pandora	7.48	10.40	8.65	14.65	4.83	9.02	8.14	5.88	6.91	10.05	10.56		
OMI	8.22	9.60	8.36	15.00	5.97	13.60	15.00	6.57	7.04	15.00	9.6	7.64	
Diff %	**-9%**	**8%**	**3%**	**-2%**	**-21%**	**-17%**	**-59%**	**-11%**	**-2%**	**-40%**	**9%**		**- 1.35 (- 12.8%)**

Column NO2 and O3 from the Pandora spectrometers

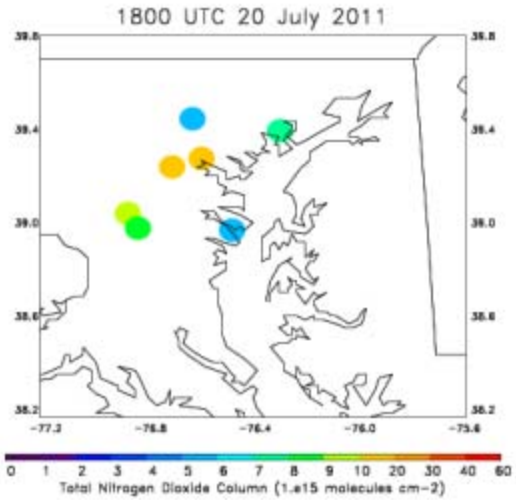


Spatial and Temporal Variability in Column NO2

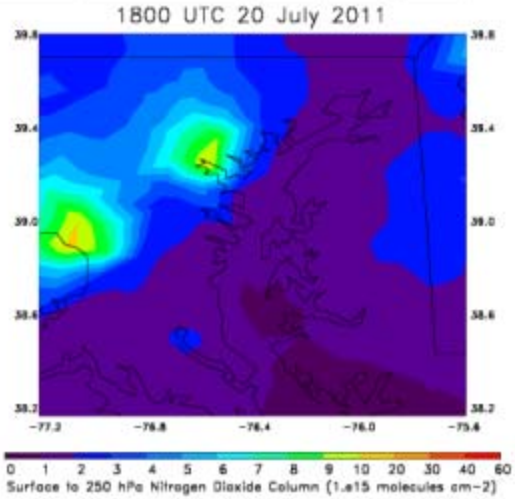
OMI satellite data (total column)



Pandora Ground Based (total column)



CMAQ model (tropospheric column)



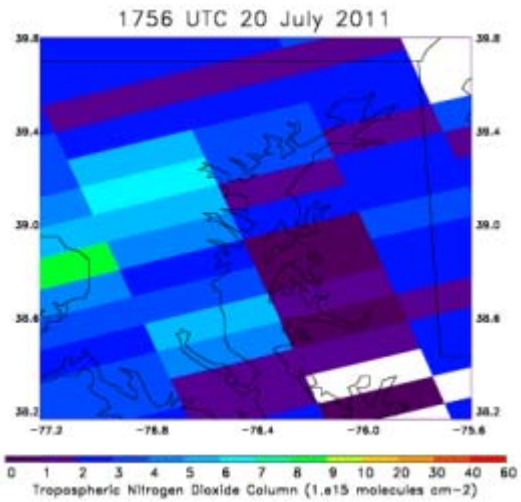
→ Overall good agreement between Pandora, CMAQ, and OMI (when small satellite footprint)

→ OMI does not always capture spatial variability shown in CMAQ and Pandora (especially when large footprint)

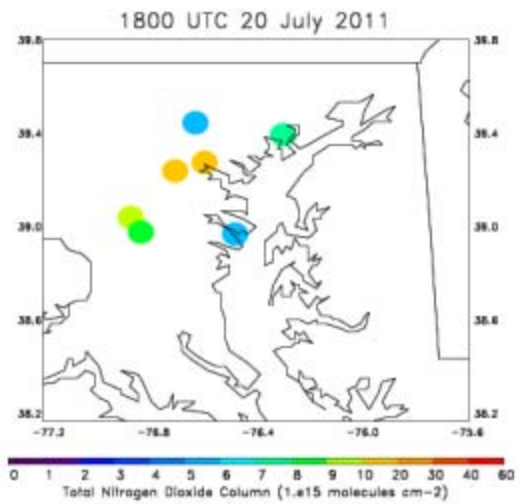
→ OMI frequently underestimates NO2 over polluted urban areas (e.g. Baltimore, Greenbelt, UMCP), while it overestimates NO2 along the Chesapeake Bay shoreline (e.g. Pandora SERC) and over the Bay (CMAQ results)

Spatial and Temporal Variability in Column NO2

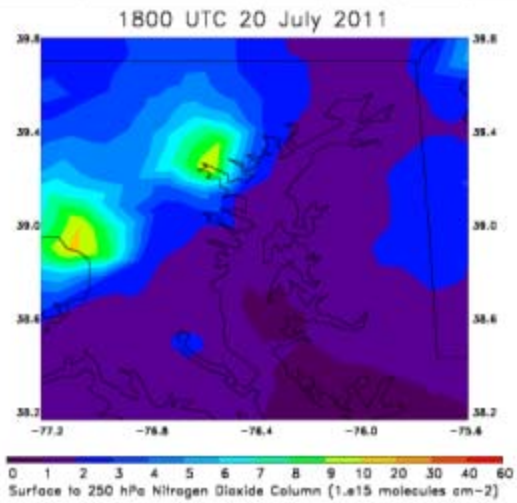
OMI satellite data (tropospheric column)



Pandora Ground Based (total column)



CMAQ model (tropospheric column)



→ The OMI "Tropospheric NO2" product is typically lower than CMAQ tropospheric NO2 column, and does not capture spatial gradients observed by Pandora.

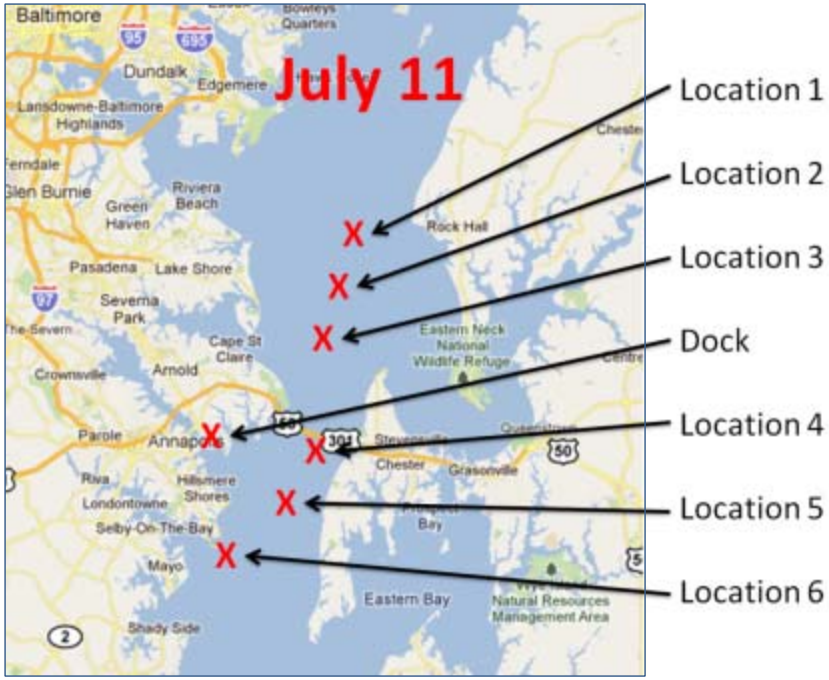
→ Compared to CMAQ, OMI systematically underestimates tropospheric NO2 over the Baltimore and Washington urban areas.

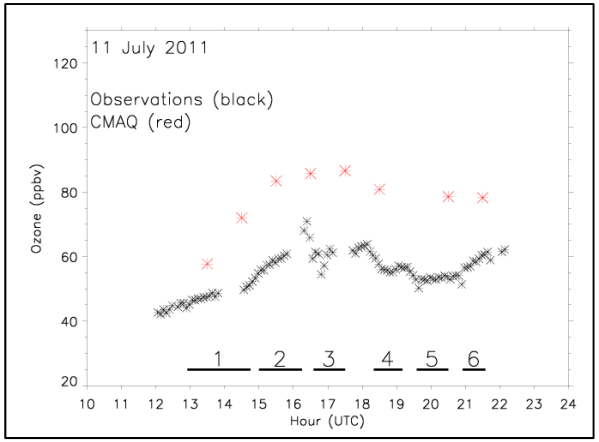
→ When large satellite footprint, OMI overestimates tropospheric column NO2 over the Chesapeake Bay.

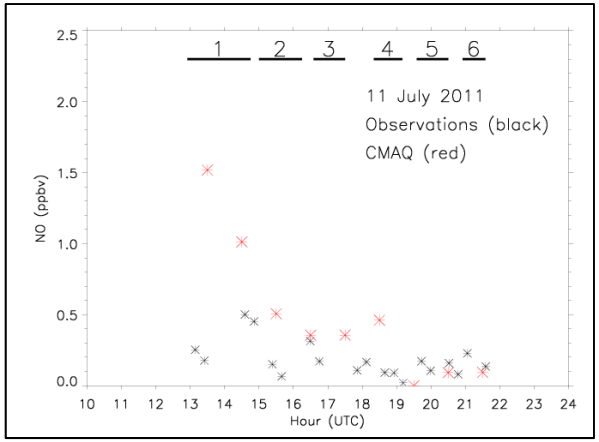
Surface O3, NO, NOy using in-situ sensors
PI: Russ Dickerson

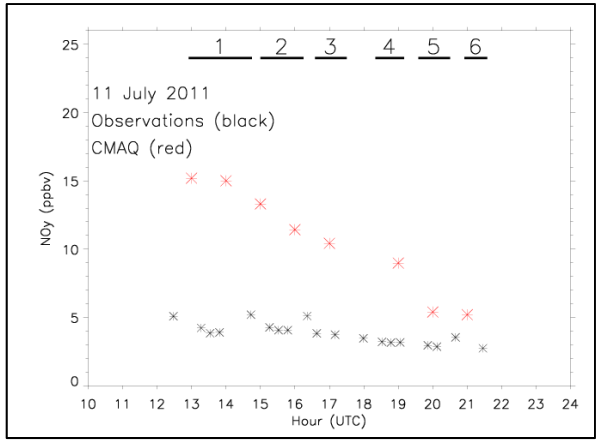
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 11 - T1 transect – Upper Bay
(DISCOVER AQ flights)





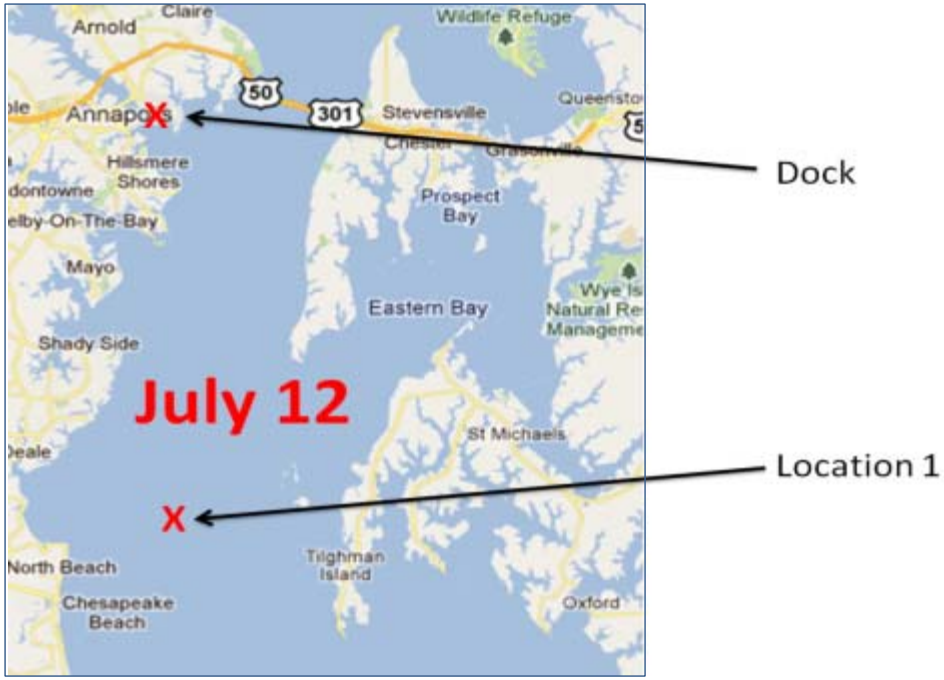


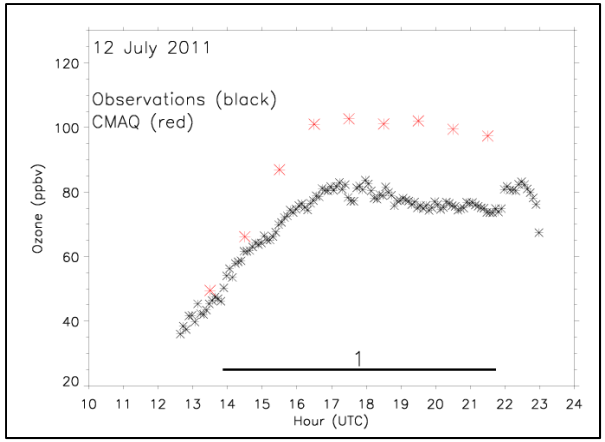


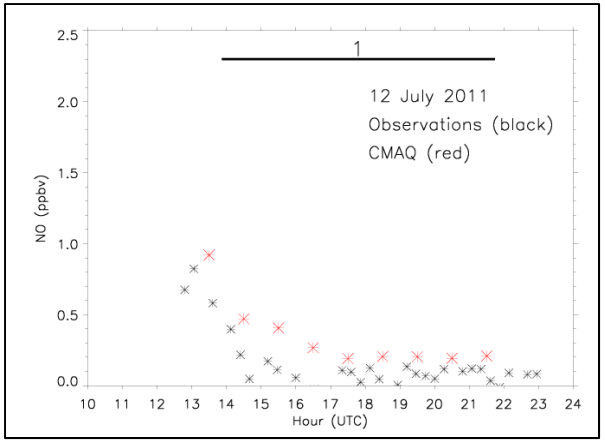
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

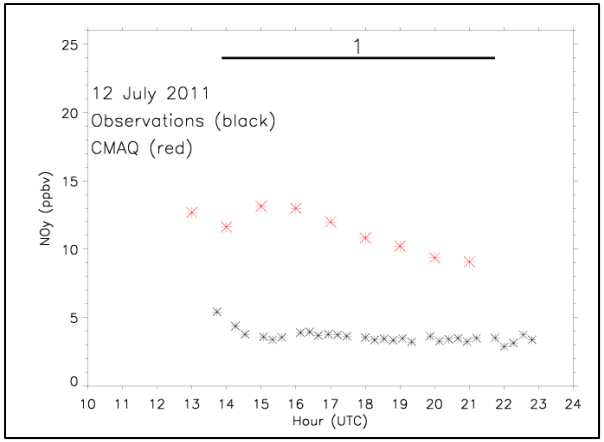
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 12 - S1 Stationary diurnal sampling (near T2-1)





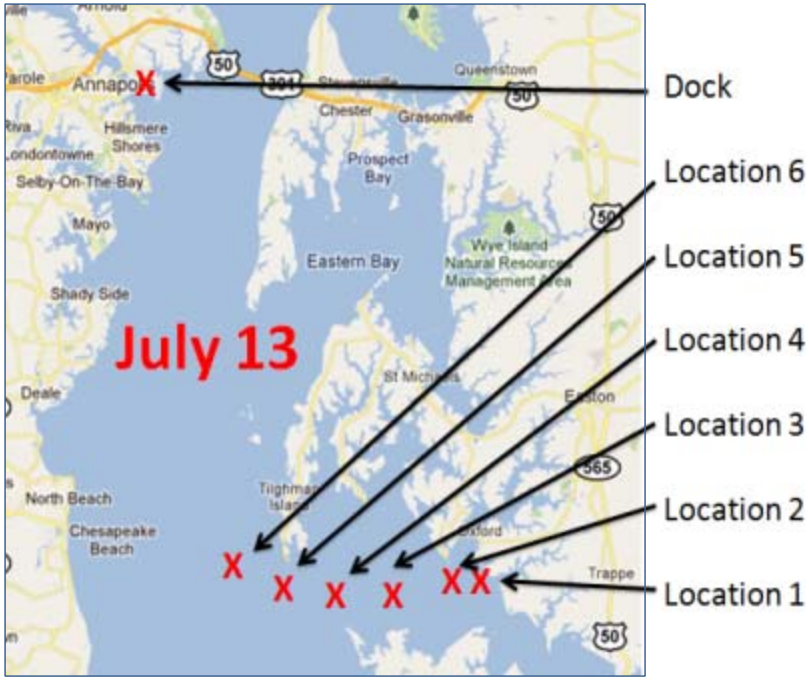


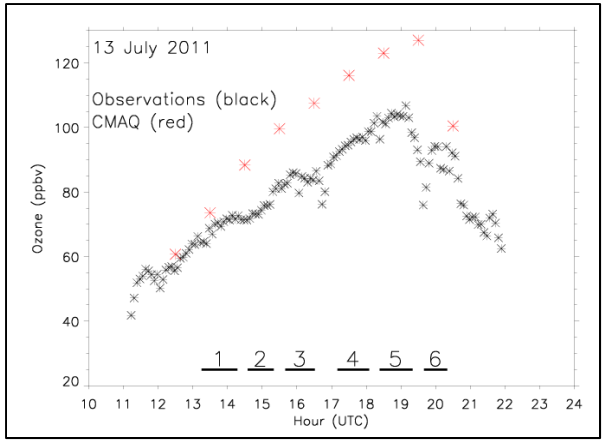


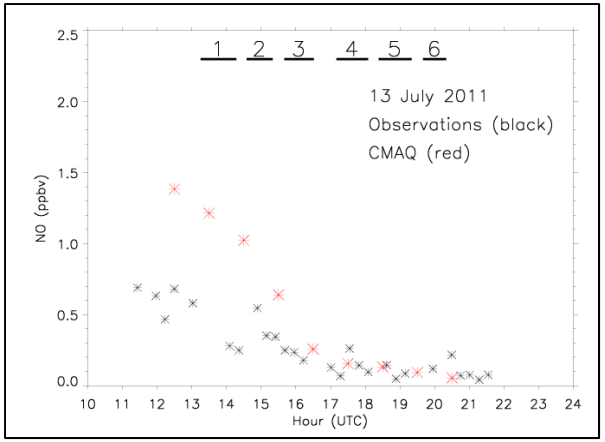
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

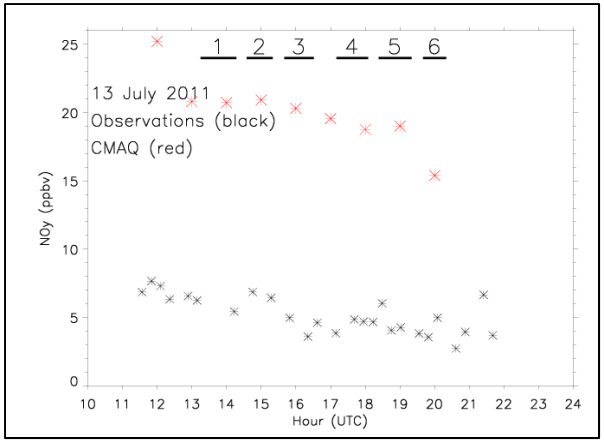
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 13 - T4 transect in Choptank River/estuary





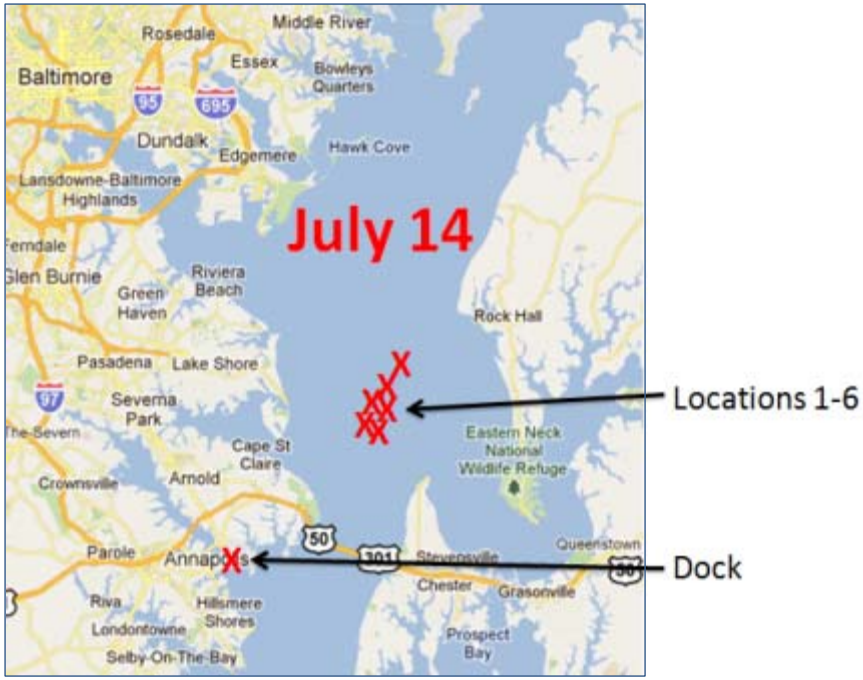


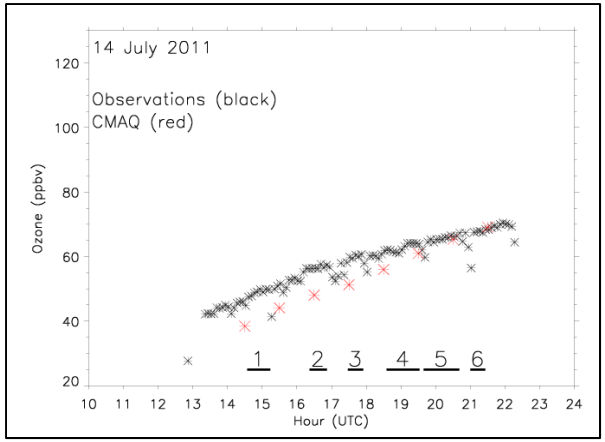


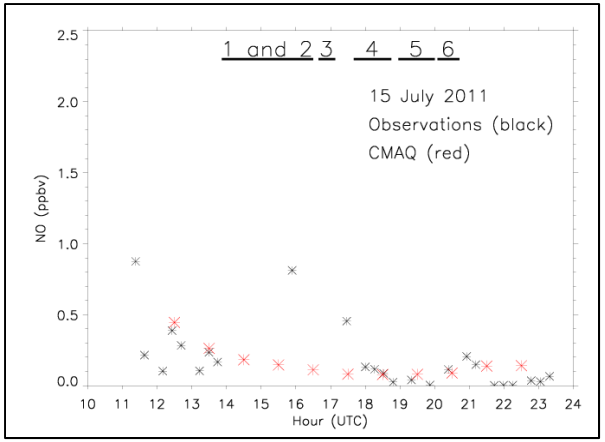
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

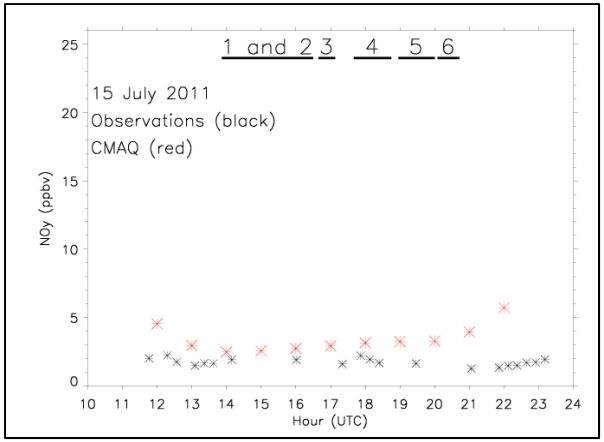
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 14 - D1 drifter in upper bay
(DISCOVER AQ flights)





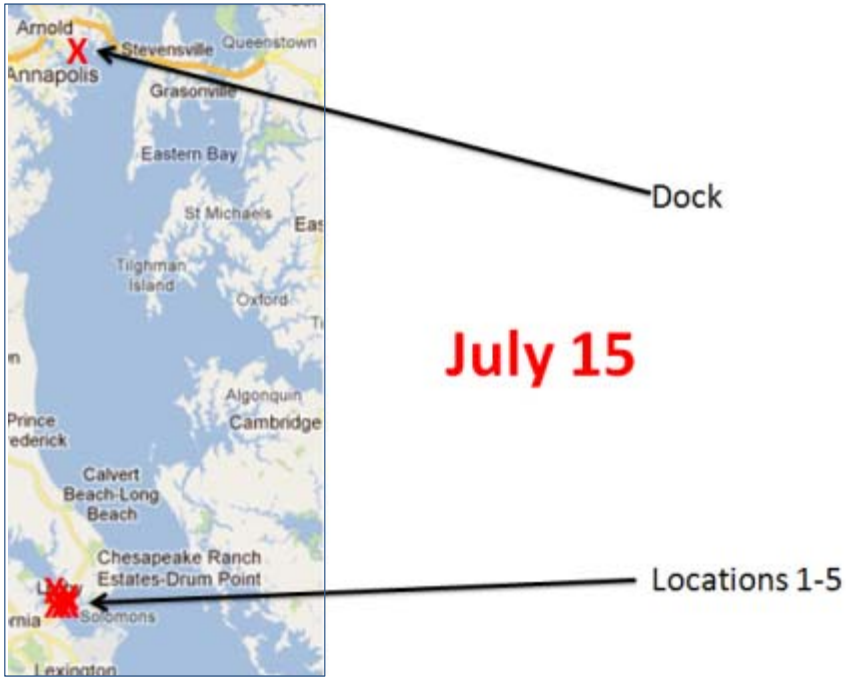


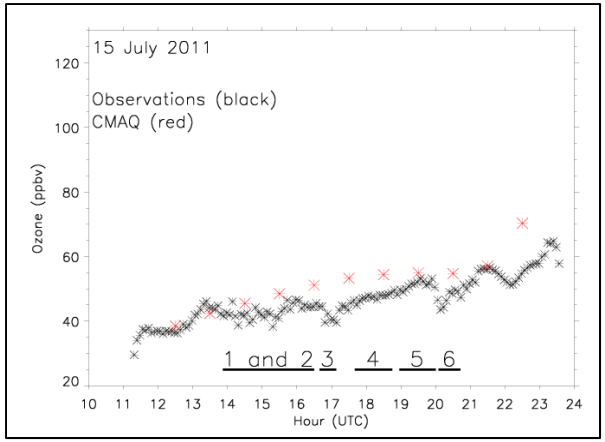


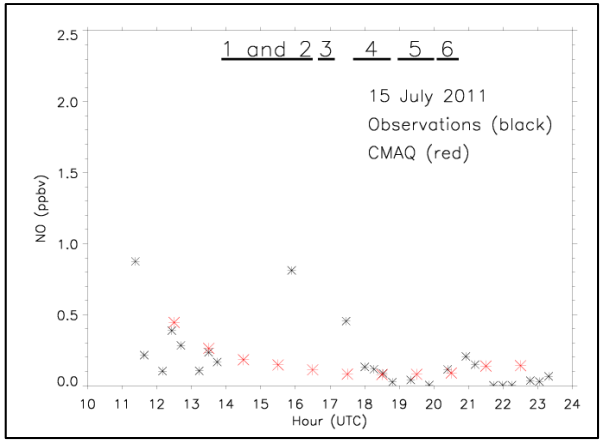
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

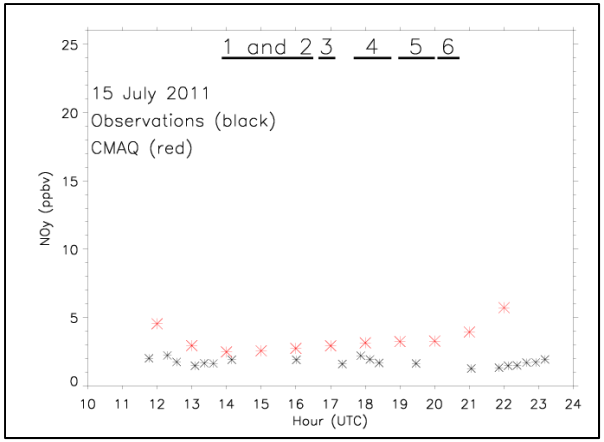
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 15 - D2 drifter in lower Patuxent River
Micro-pulse Lidar installed in the evening





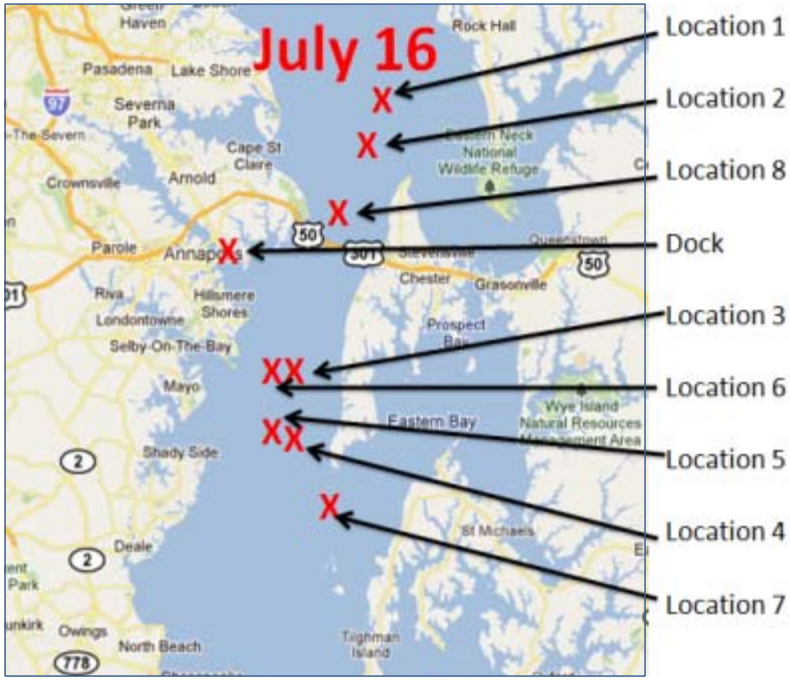


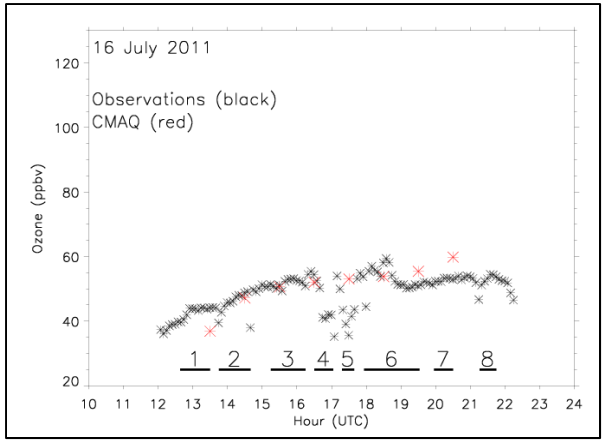


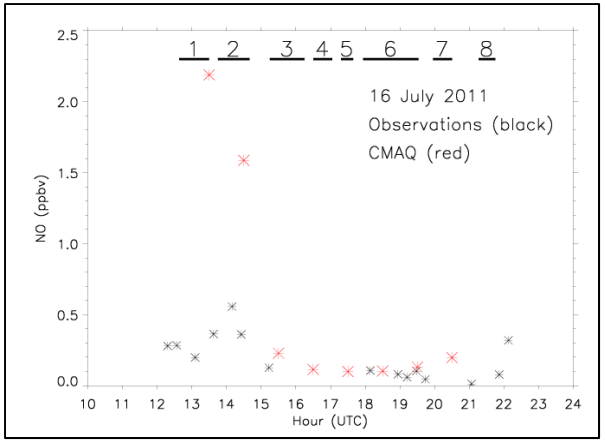
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

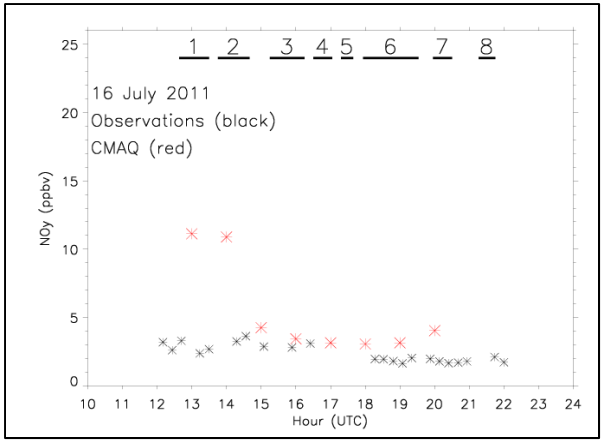
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 16 - T5 transect in Upper Bay
(DISCOVER AQ flights)





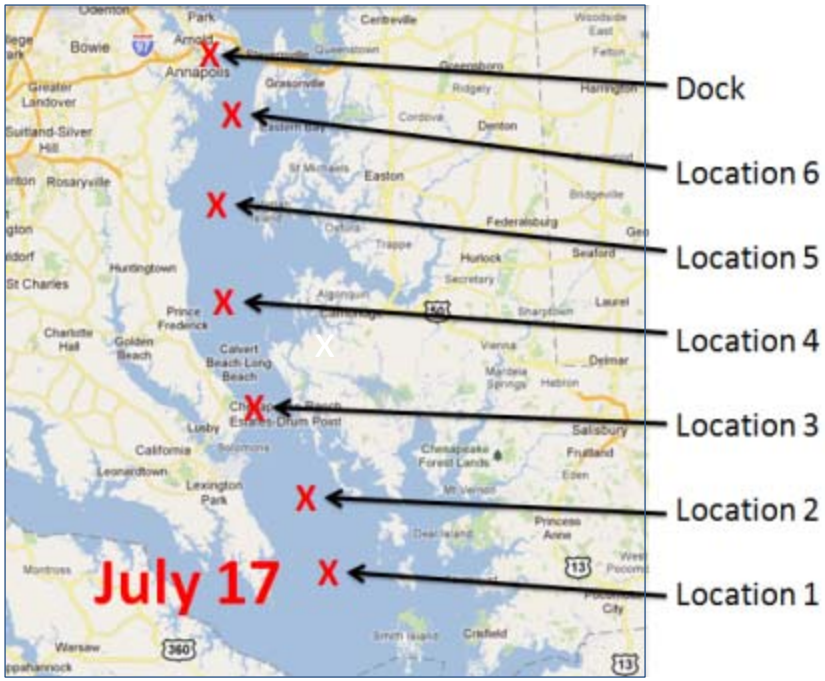


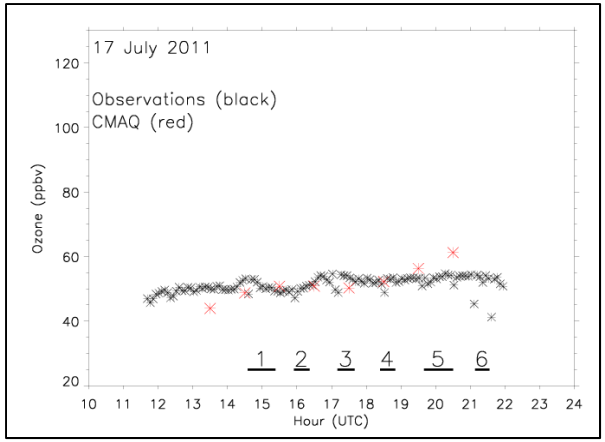


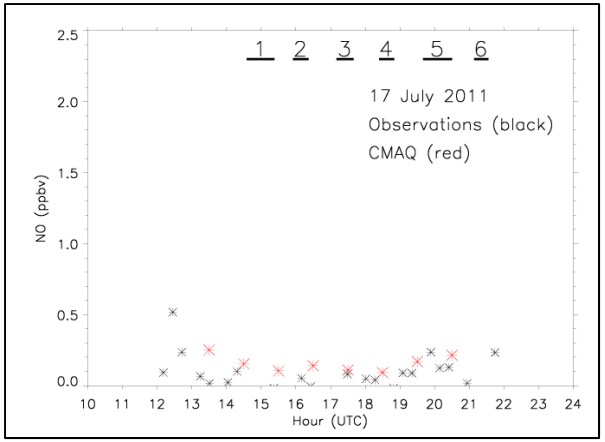
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

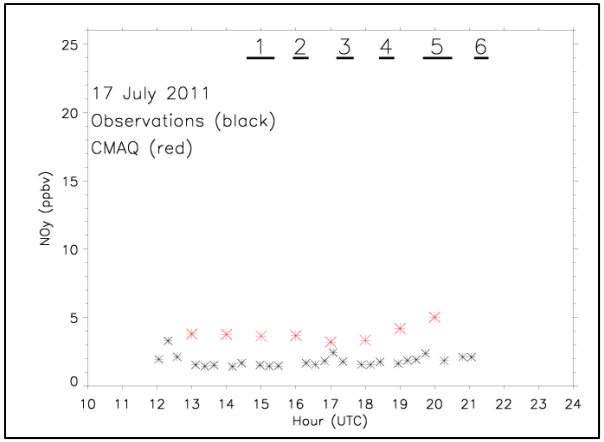
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 17 - T2 transect in Mid Bay (starting from Annapolis and going south close to the mouth of the Patuxent river)





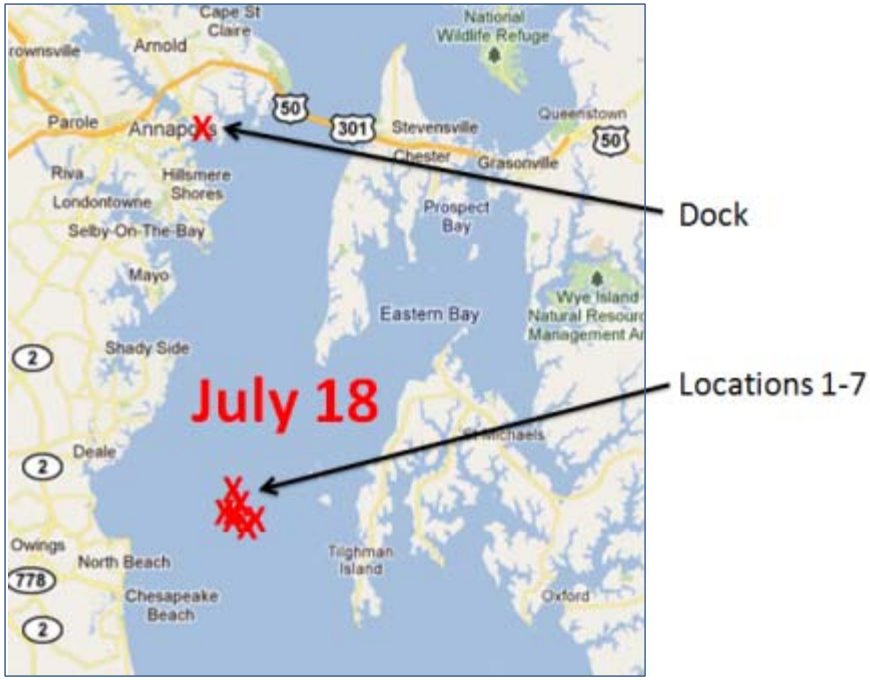


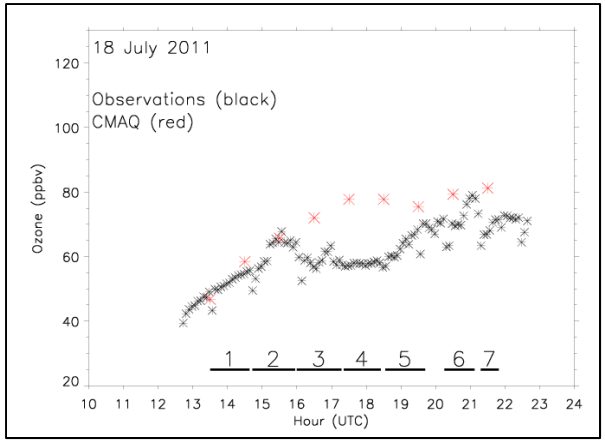


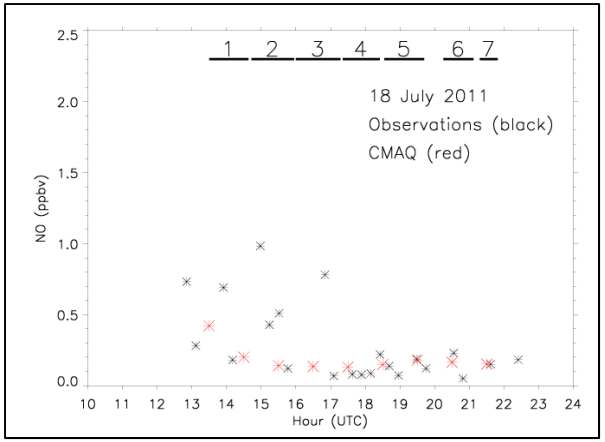
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

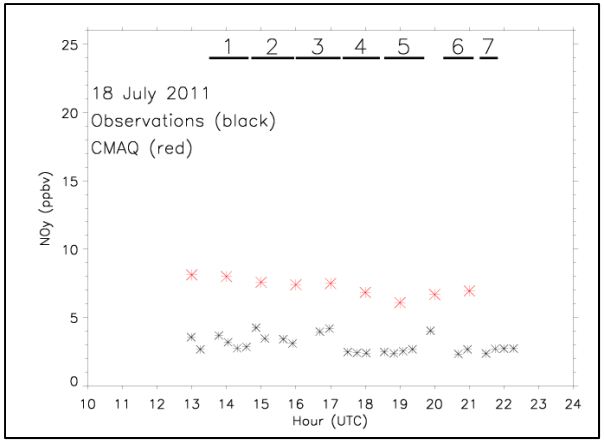
Variability in surface O3, NO, NOy over the Chesapeake Bay

July 18 - D3 Drifter at T2-2 station
(DISCOVER AQ flights)





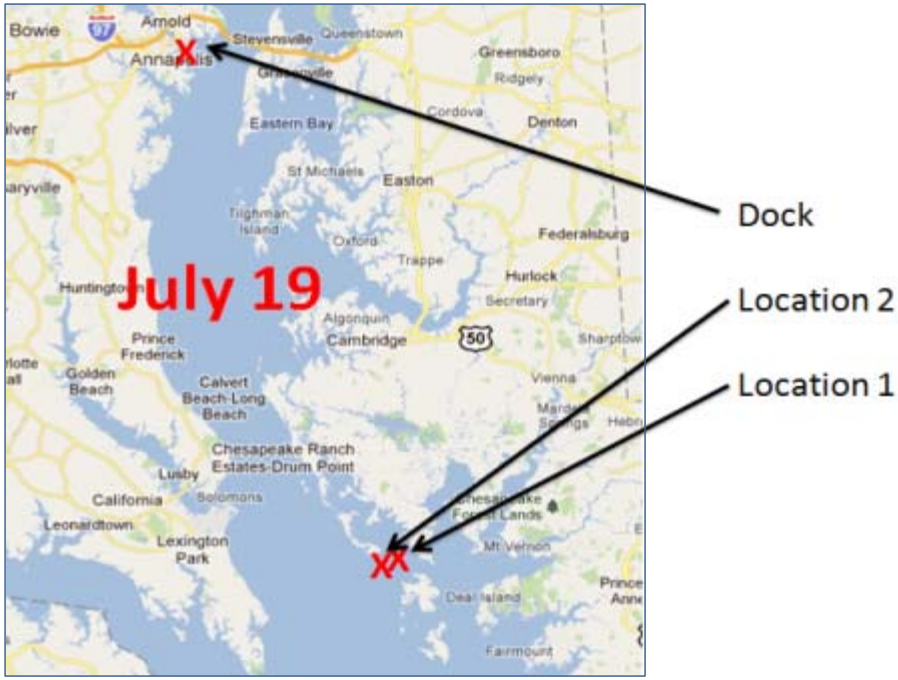


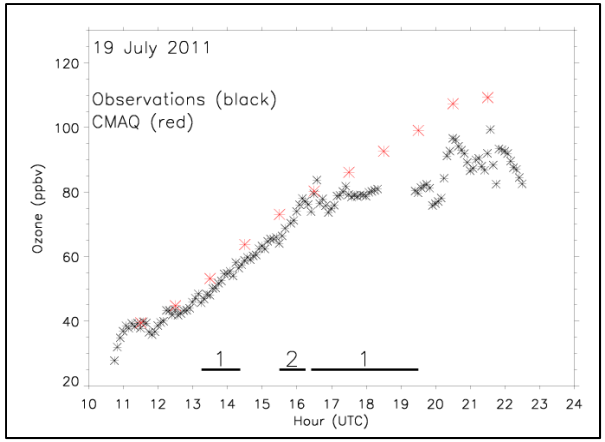


Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

Variability in surface O3, NO, NOy over the Chesapeake Bay

July 19 - T3 transect in Blackwater Wildlife Refuge marsh
Transect with zodiac and stationary sampling from the ship

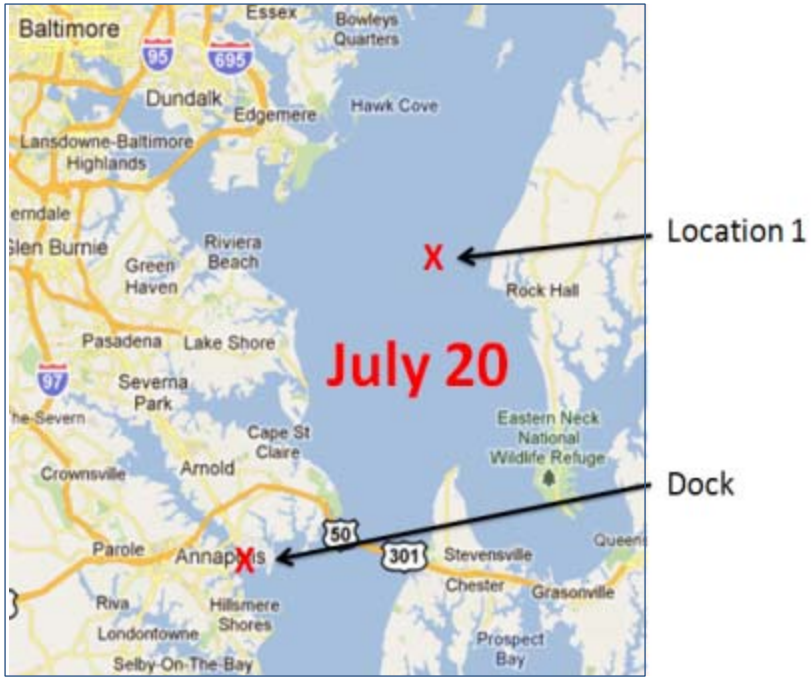




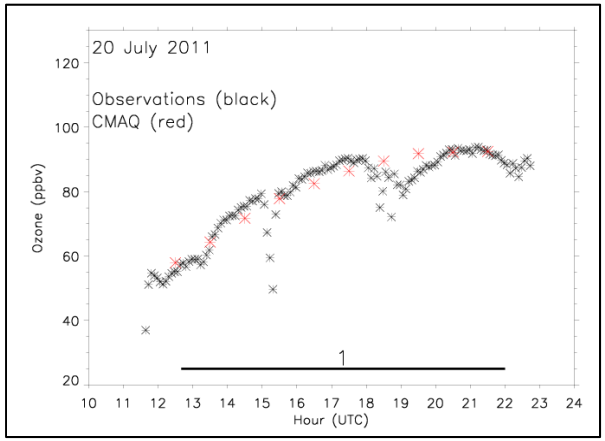
Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

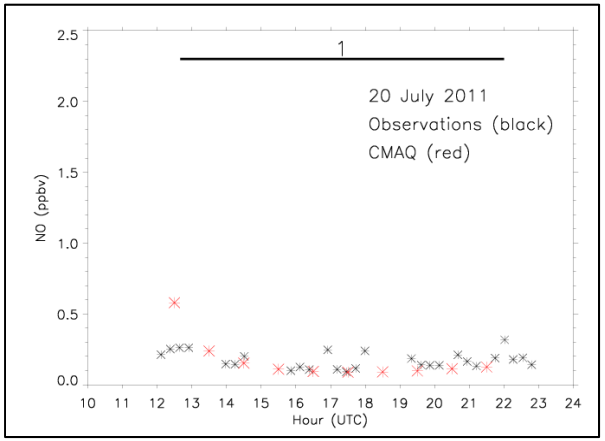
Variability in surface O3, NO, NOy over the Chesapeake Bay

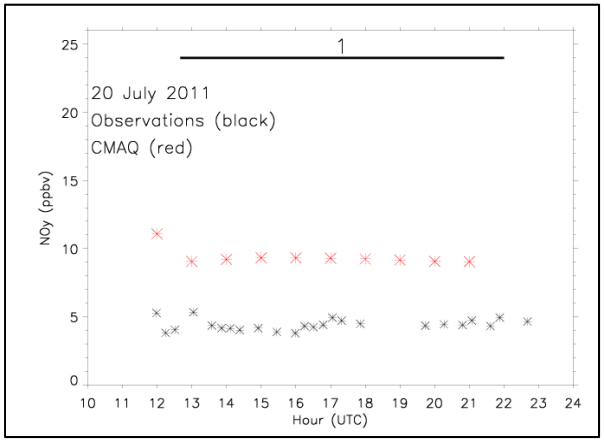
July 20 - Stationary diurnal sampling at S3 station
(DISCOVER AQ flights)



→ Overall good agreement for O3 and NO between CMAQ and sensors
→Not good agreement for NOy
→ Large variability (up to 60-80 ppbv), both spatially (transect measurements) and temporally (day-to-day and diurnal), both in measurements and model simulations







Data from Dan Goldberg
Contact: ***dgoldb@atmos.umd.edu***

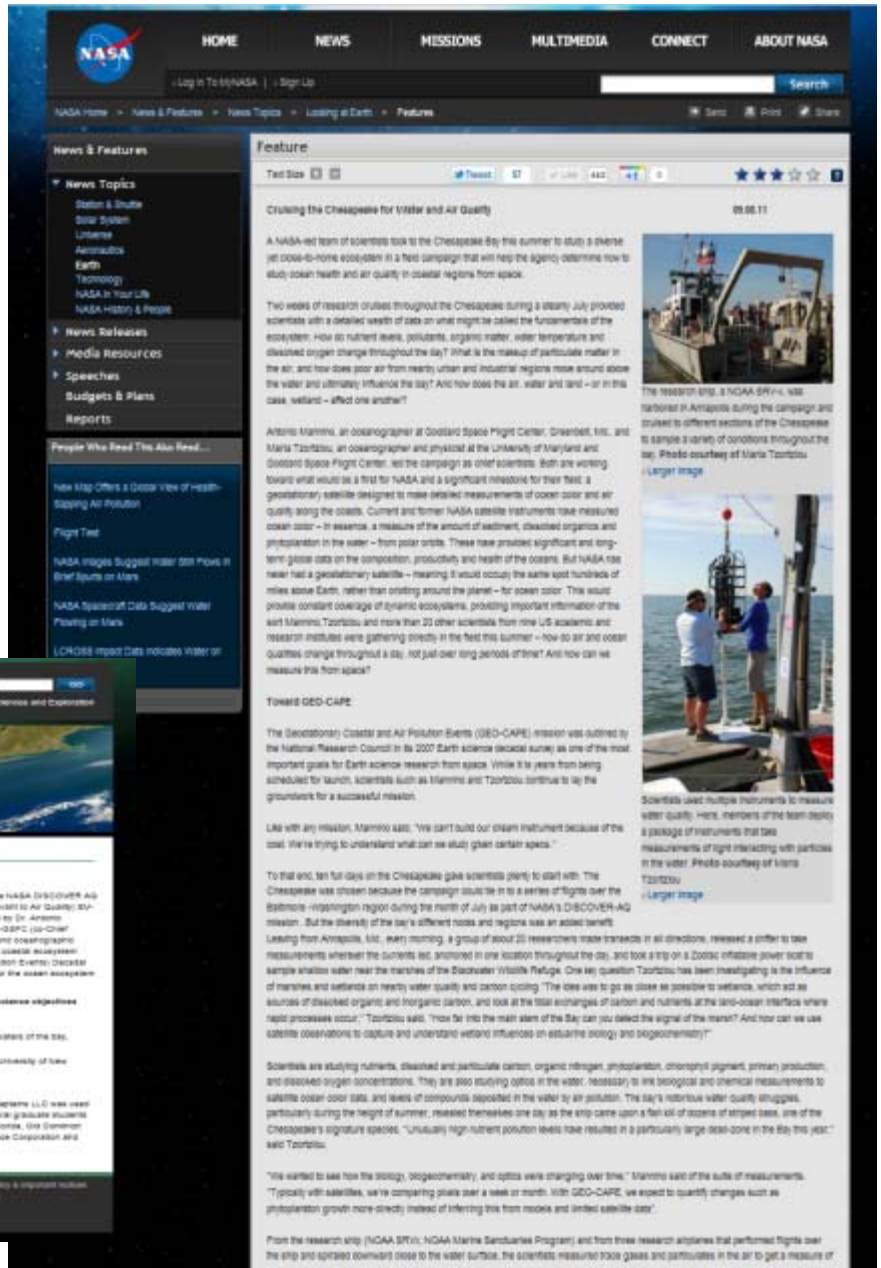
SUMMARY

- Feature articles highlighting the CBODAQ activities appeared on:
  → NASA Earth News & Features
  http://www.nasa.gov/topics/earth/features/chesapeake-quality.html
  → the Smithsonian Institution News and Highlights
  http://sercblog.si.edu/?p=1376

- We have created a **GEO-CAPE CBODAQ website** for posting information and data from the cruise:
  http://geo-cape.gsfc.nasa.gov/.

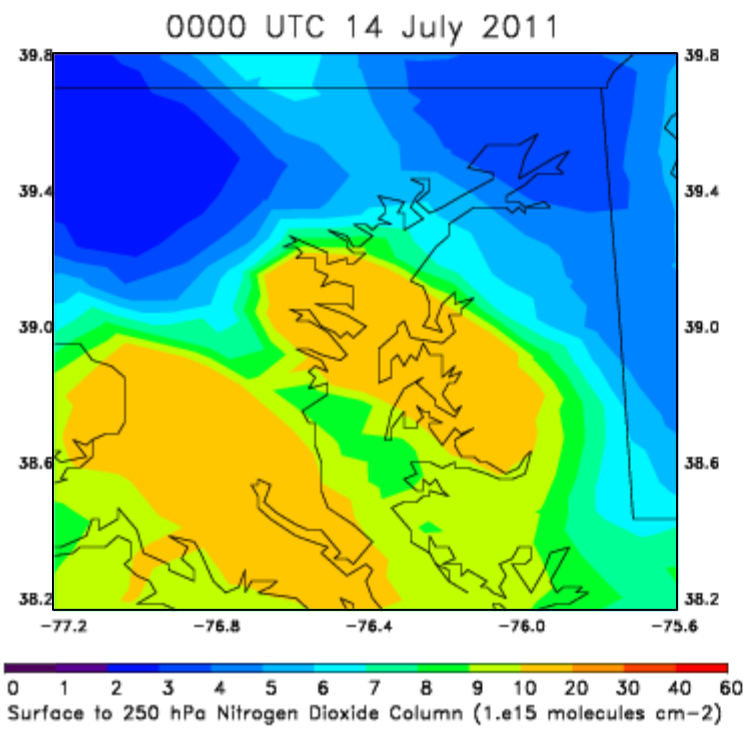
- All collected data will be uploaded on the **NASA SeaBASS ocean color database (by end of February)**.

- The atmospheric data from the ship will be put on the **DISCOVER-AQ archive.**

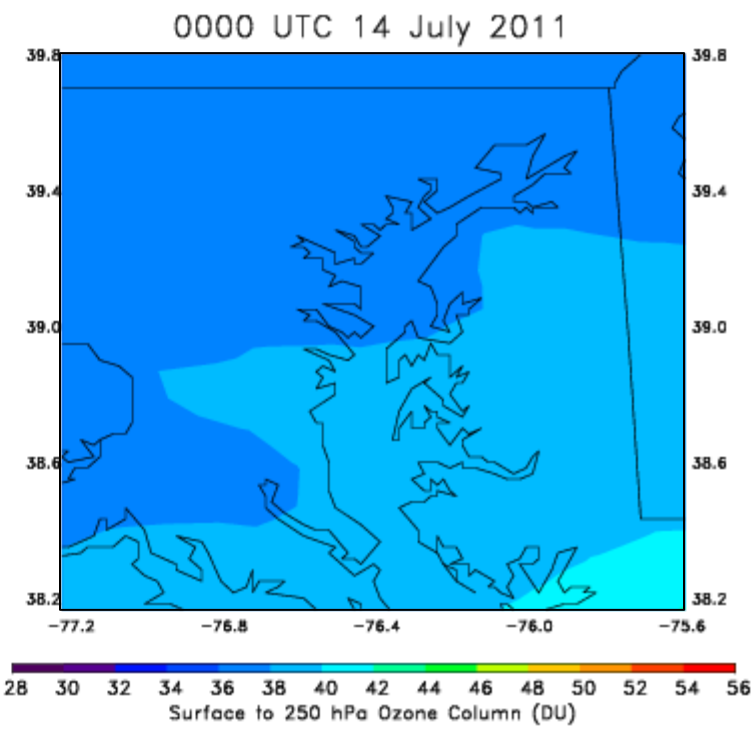


Diurnal Variability in Tropospheric NO2 and O3 over the Chesapeake Bay

CMAQ NO2 (Surface to 250 hPa)



CMAQ O3 (surface to 250 hPa)



→ Significant variability, **of the order of 0.5 to 1.0 DU**, in tropospheric NO2 over the Chesapeake Bay estuarine waters during the day
→ High NO2 in the north Ches Bay , lower in the mid-Bay with larger variability
→Variability in column O3 as well

→ Variability was also found on **surface NO, NOy and O3** (up to 60-80 ppbv), both spatially (transect measurements) and temporally (day-to-day and diurnal), both in measurements and model simulations