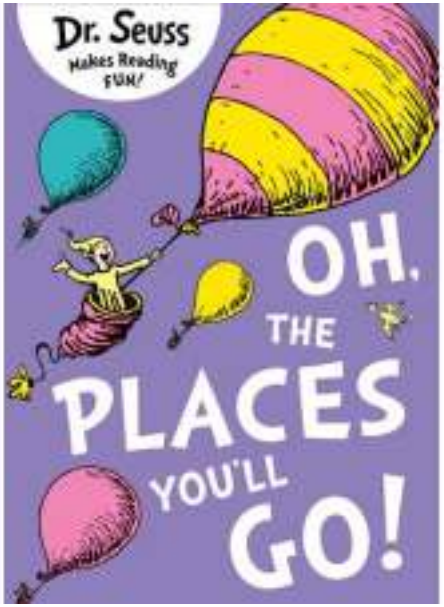
PBL Workshop Instrument Track: Tropospheric Ozone Lidar



J. Sullivan, T. McGee, L. Twigg, G. Sumnicht,
and many others…

Howard University Virtual PBL Workshop

Summer 2020

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Roadmap

- Introduction
- O_3 DIAL 101
- Versatility of O_3 DIAL
  - Mountain-Plains Recirculation (DISCOVER-AQ)
  - Stratospheric-Tropospheric Exchange (DISCOVER-AQ)
  - **Nocturnal Low Level Jets (MDE)**
  - Sampling the Seoul Plume (KORUS-AQ)
  - Ozone Land-Water Transitions (OWLETS 1/2)
- Summary and Future Work

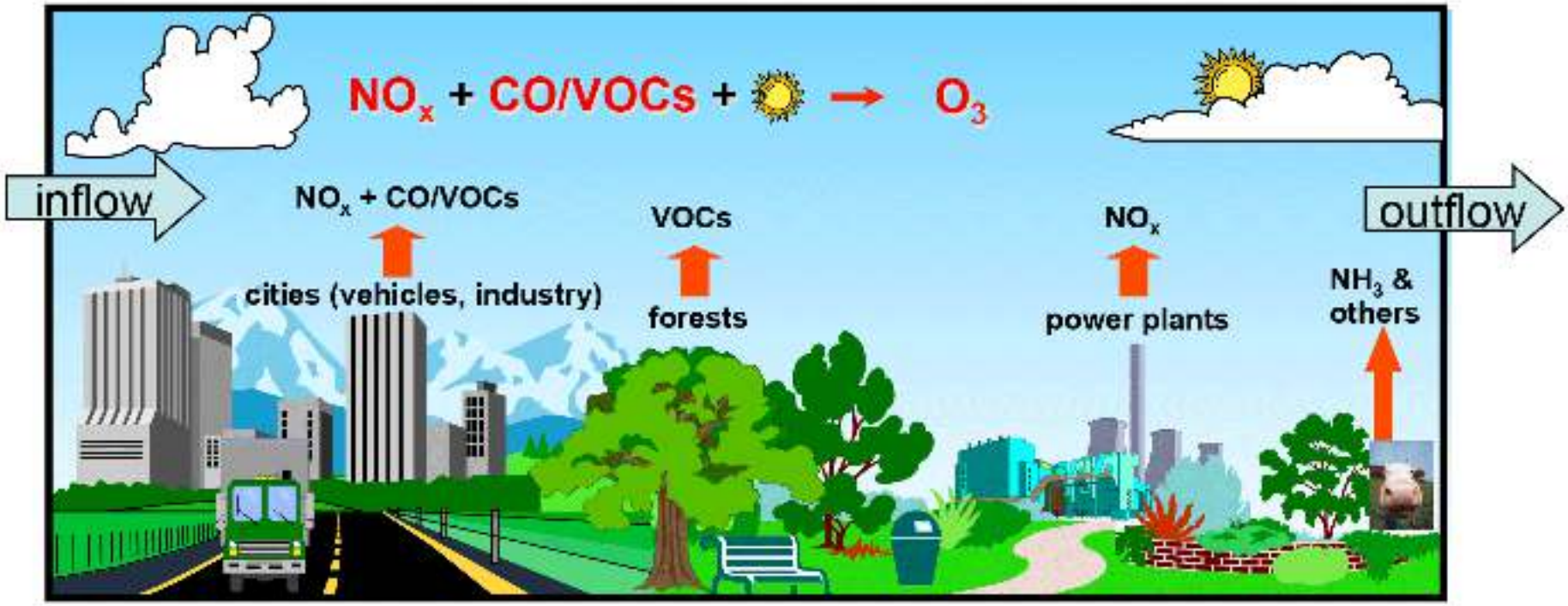
Tropospheric O_3

- toxic to humans and vegetation
- continuous EPA monitors at the surface are not able to monitor aloft sources of O_3 (8-hr standard is 70 ppbv
  - O_3-sonde launches are valuable, but intensive and costly
- greenhouse gas (impact largest in free troposphere)
- As per 2017 Nat. Ac. Sci. decadal survey – still a high priority

(figure courtesy National Park Service, www.nature.nps.gov)

Tropospheric O_3

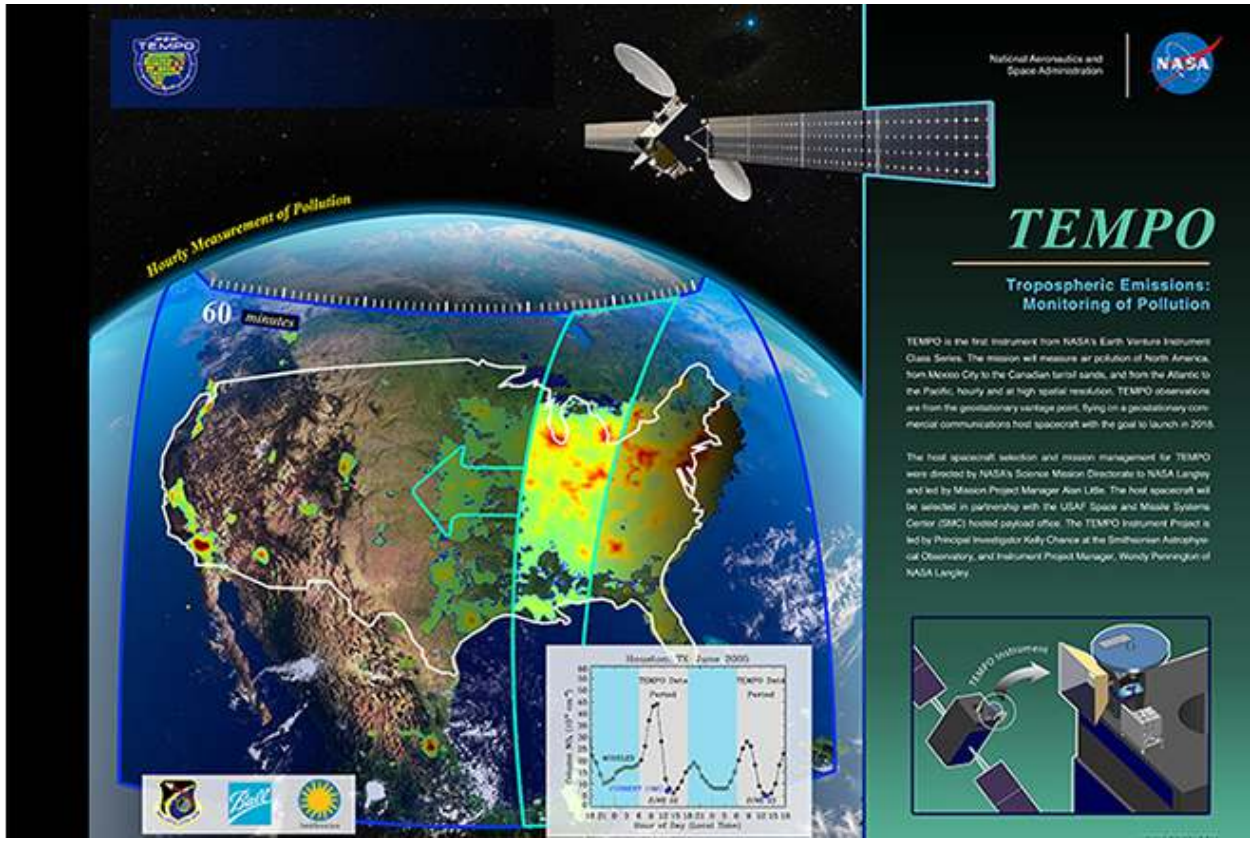
- non-linear chemistry, photochemical/diurnal cycle
- ***Secondary*** pollutant, meteorology drives production



(figure courtesy NOAA ESRL, www.esrl.noaa.gov)

Tropospheric Emissions: Monitoring of Pollution (TEMPO)

- **Delivery in 2018, launch in 2020-2021 timeframe**
- **TEMPO will be the first geostationary air quality satellite for North America to provide hourly measurements throughout the U.S. for key trace gases**
- **generate 0–2 km O_3, free tropospheric O_3, and total column**
- **Observations of ozone and other constituents in complex coastal regions are critical for TEMPO validation and improvement in its data product retrievals**



TEMPO Mission

Principal Investigator: Kelly Chance, Smithsonian Astrophysical Observatory
Instrument Development: Ball Aerospace & Technologies Corporation
Project Management: NASA/Langley Research Center

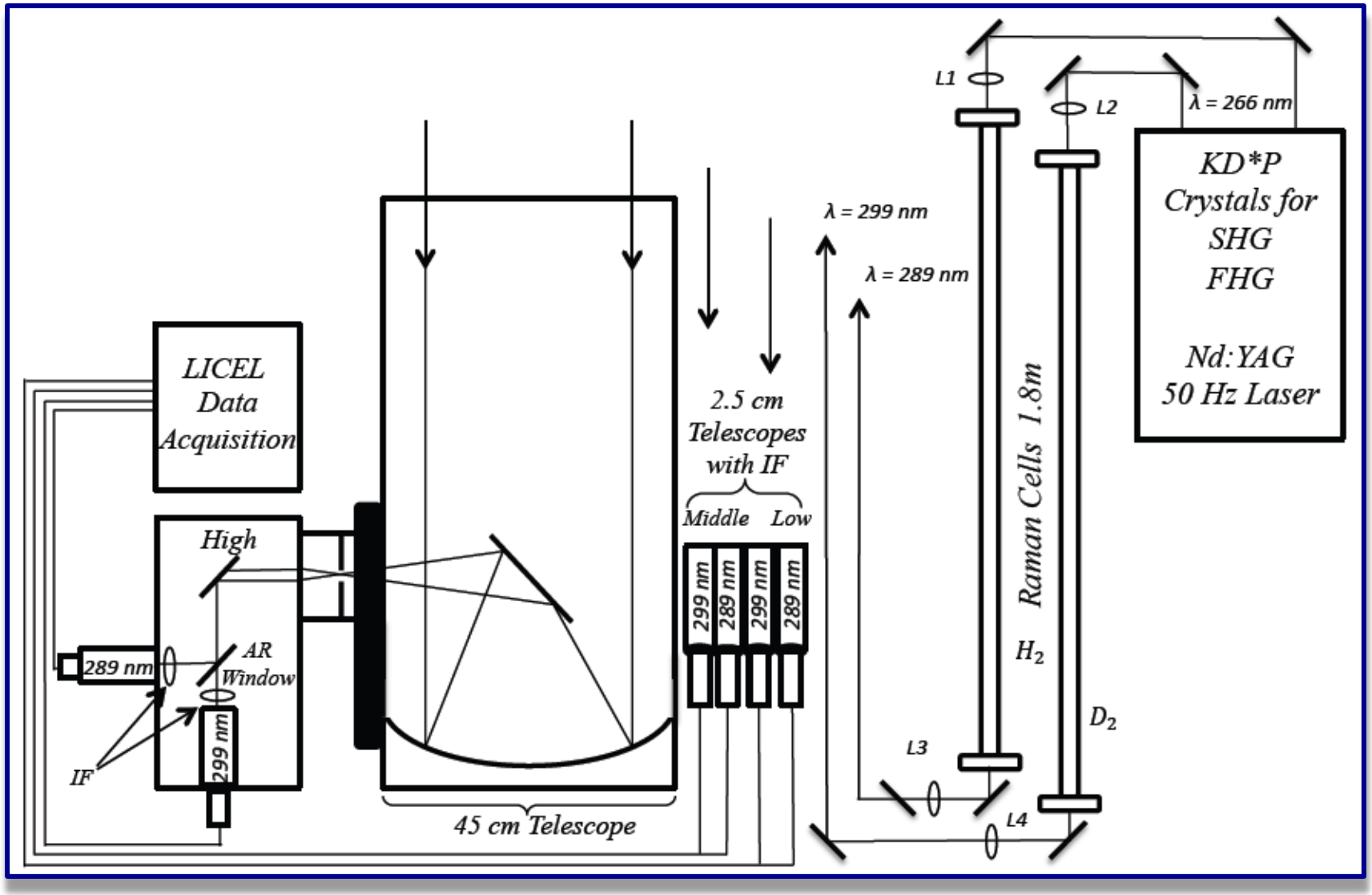
For more information and data, visit - http://tempo.si.edu/overview.html

TOLNet

- Ground based ozone lidar network consisting of 6 stations –funded initially in 2011
  - 4 Mobile/Transportable, 1 Fixed, 1 Transitioning
- Emphasis on improving overall understanding of air quality episodes and satellite retrievals in future satellite missions (*e.g.* TEMPO)

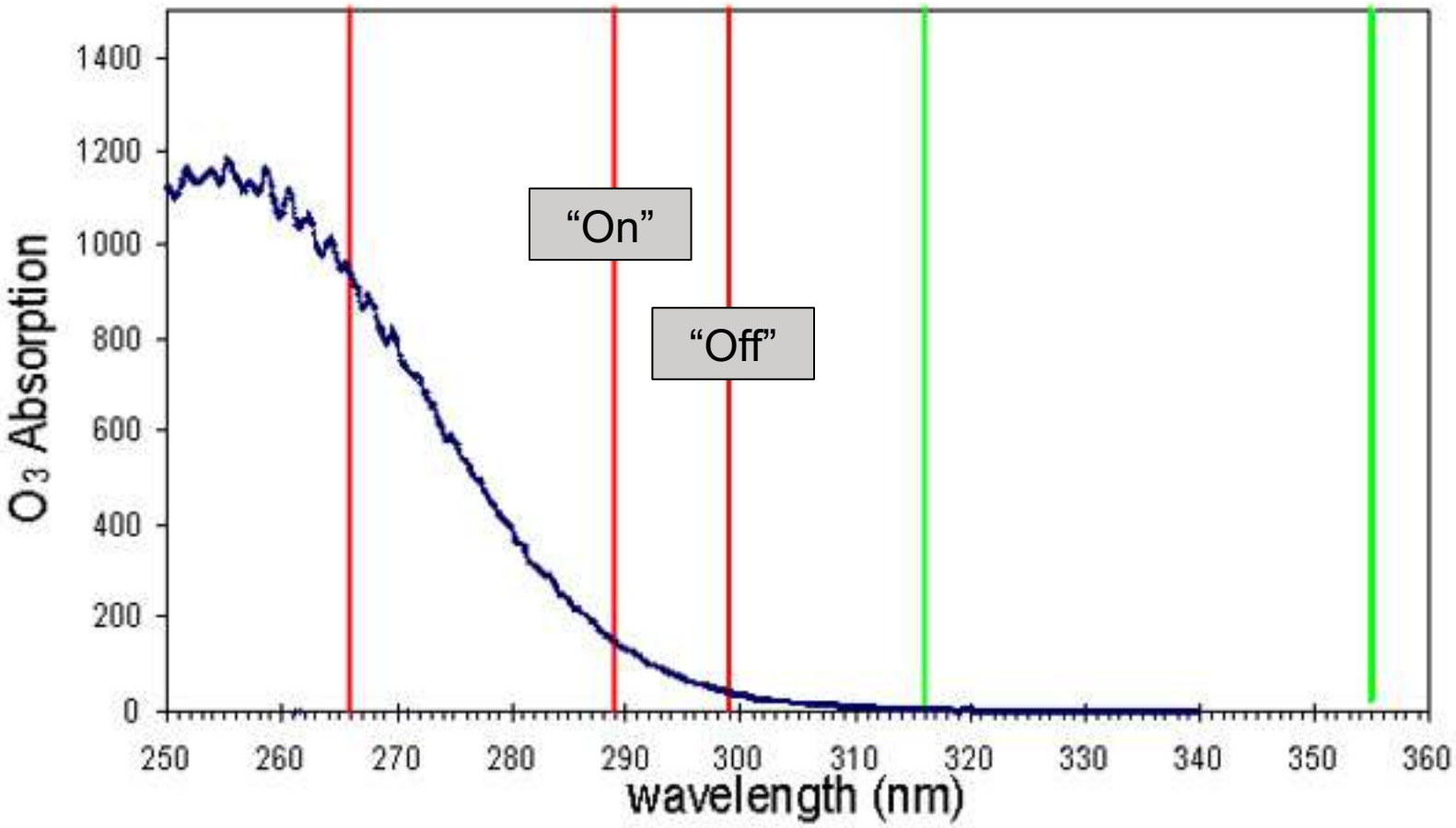
For more information and data, visit - http://www-air.larc.nasa.gov/missions/TOLNet/

GSFC TROPOZ



Sullivan et al. Mobile Tropospheric Ozone Lidar in BW Region, Atmos. Meas. Tech. 2014.

Diff. Absorption (DIAL)



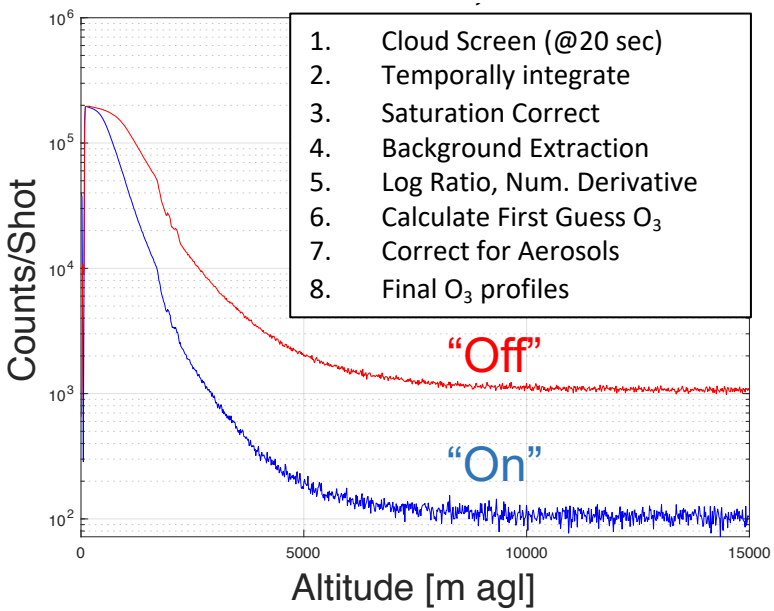
Sullivan et al. Mobile Tropospheric Ozone Lidar in BW Region, Atmos. Meas. Tech. 2014.

DIAL Equation

$$N_{o3} = \frac{1}{2\Delta\sigma_{O_3}\Delta r}[\ln(\frac{P_{off}(r+\Delta r)}{P_{off}(r)}\frac{P_{on}(r)}{P_{on}(r+\Delta r)}) - \ln C] - D$$

$$C = \frac{\beta_{off}(r+\Delta r)}{\beta_{off}(r)}\frac{\beta_{on}(r)}{\beta_{on}(r+\Delta r)})$$

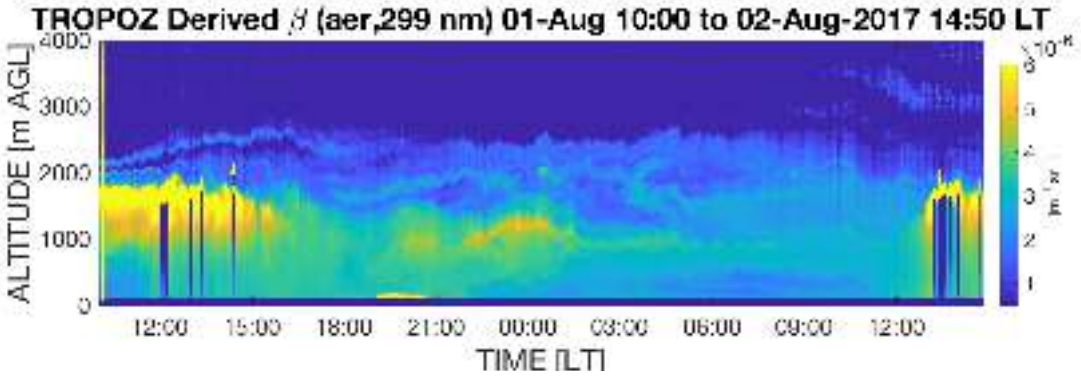
$$D = \frac{\Delta\alpha_{mol}}{\Delta\sigma} - \frac{\Delta\alpha_{aer}}{\Delta\sigma} - \frac{N_{IG}\Delta\alpha_{IG}}{\Delta\sigma}$$



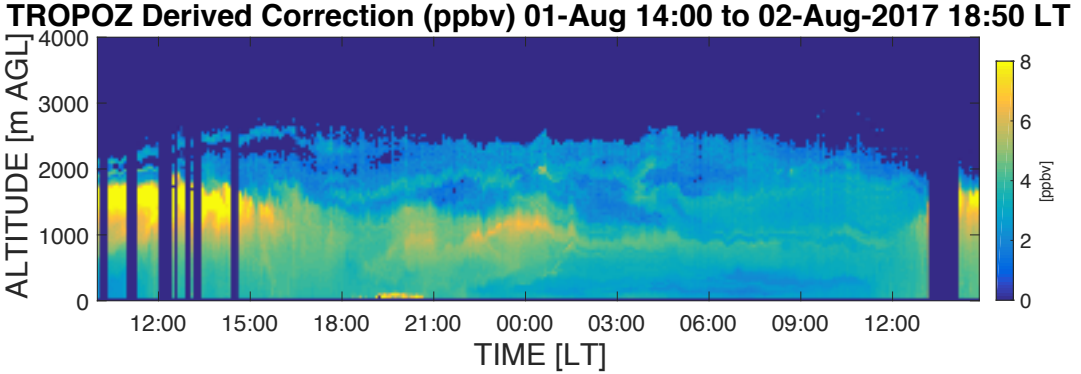
- Corrected for extinction from Molecular, Aerosol, and Interfering Gases

Sullivan et al. Mobile Tropospheric Ozone Lidar in BW Region, Atmos. Meas. Tech. 2014.

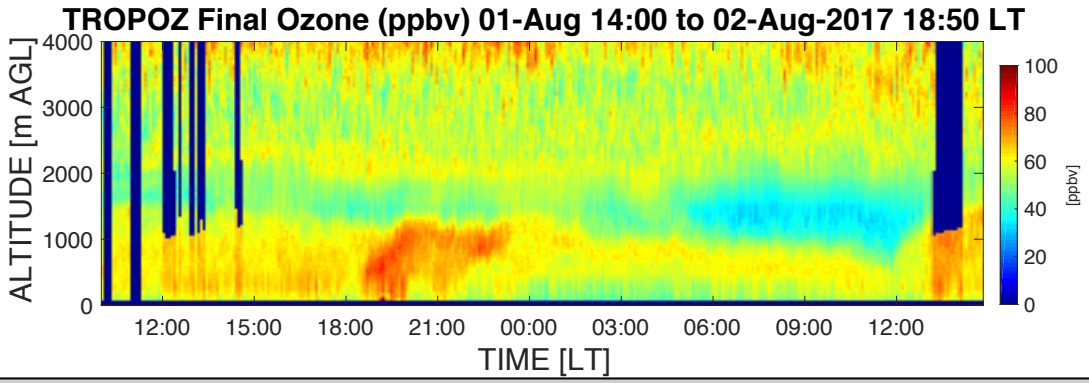
Data Example



299 nm backscatter aerosol extinction, assuming (extinction/backscatter) S_a = 40 sr; R_0 = 6 kms, with first guess O_3 and a priori



Resultant aerosol correction [ppbv], assuming power law wavelength dependence (-0.5 to -1.5) on aerosol extinction



Resultant final O_3 dataset, aerosol corrected

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

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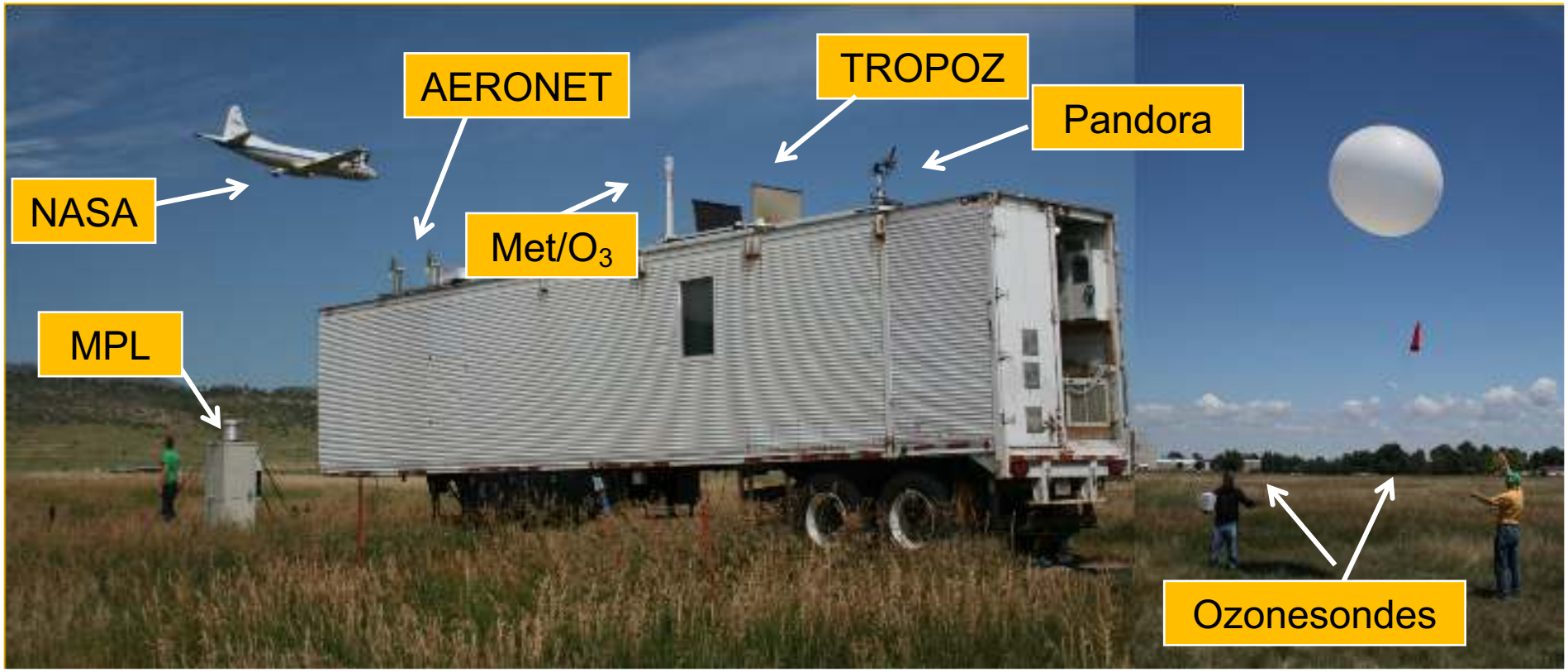
Deployment

- Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ)



John Sullivan, NASA/GSFC (photo credit: L. Twigg) *email: john.t.sullivan@nasa.gov*

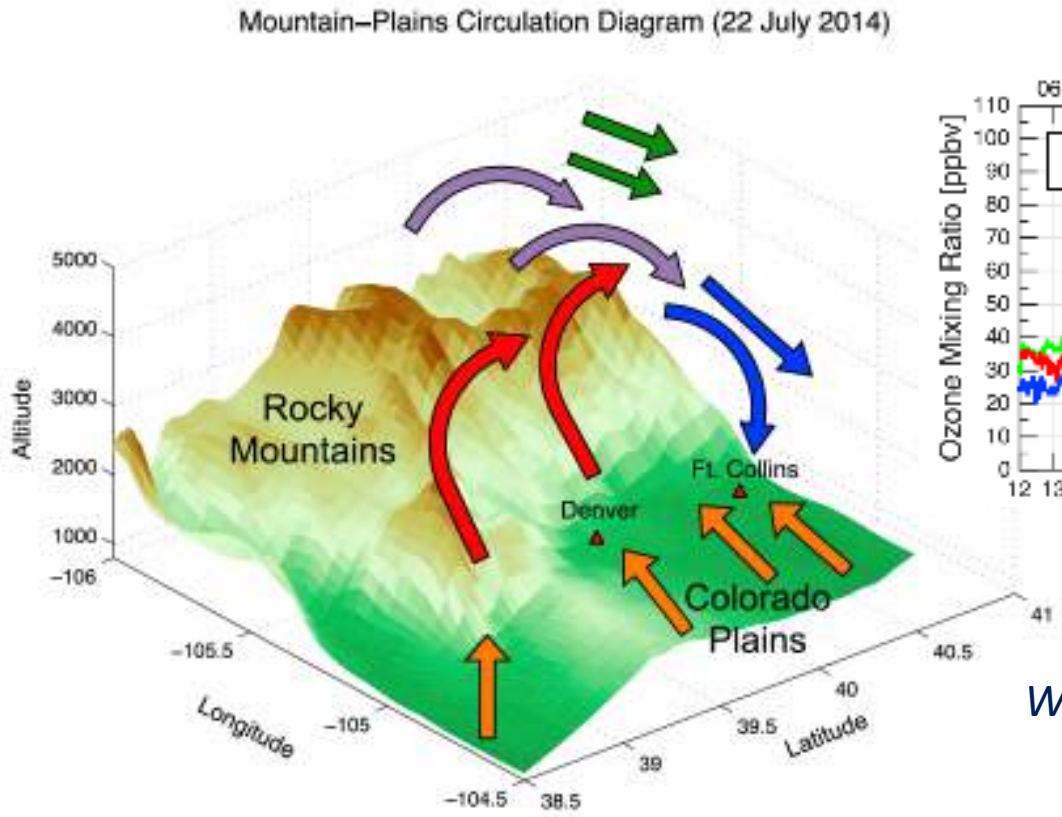
Terrain Impacts

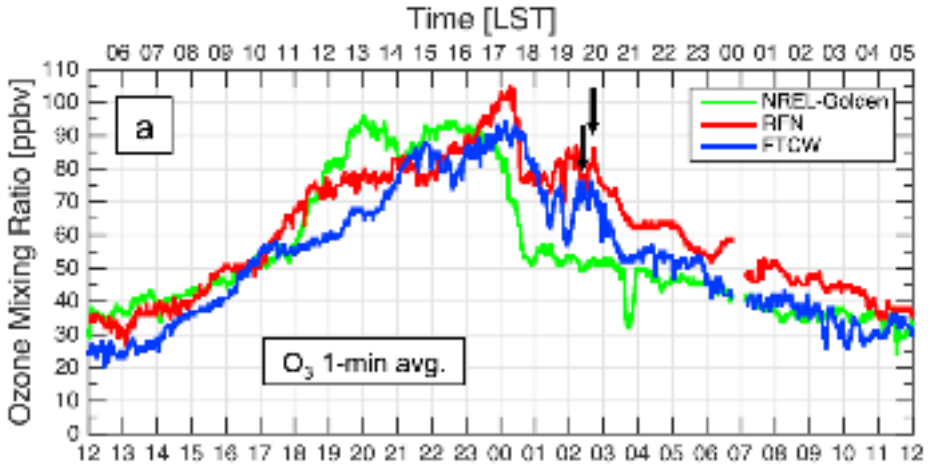
Image courtesy Colorado Department of Public Health and Environment (CDPHE)

Terrain Impacts

Image courtesy Colorado Department of Public Health and Environment (CDPHE)

Terrain Impacts



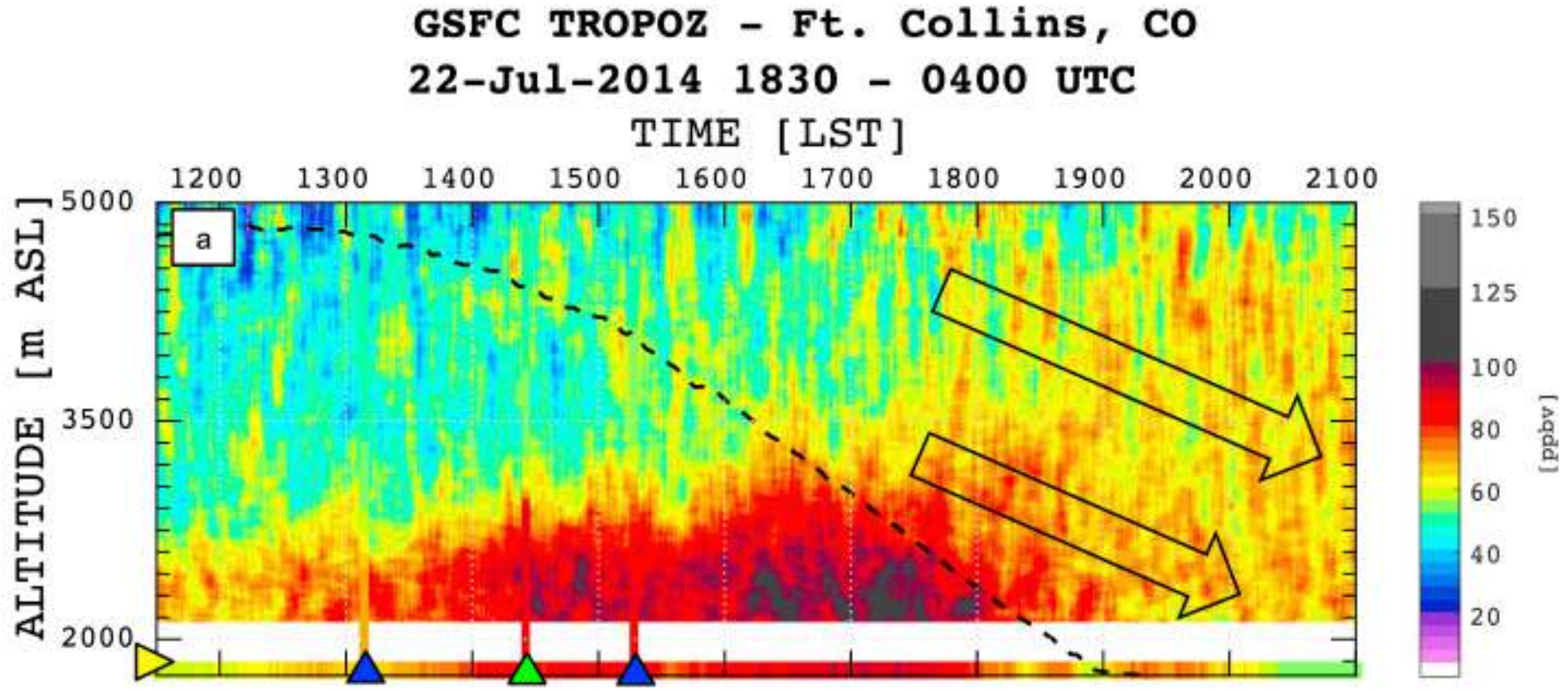


What's driving these late day O_3 peaks?

- Recirculation within the Front Range (Mountain Plains Circulation/slope flows)

Sullivan, J. T. et al., Quantifying thermally driven recirculation in Front Range, JGR Atmos, 2016

Terrain Impacts



- Revealing aloft pollution flow with lidar, in-situ, and nearby wind profiler (not shown).

Sullivan, J. T. et al., Quantifying thermally driven recirculation in Front Range, JGR Atmos, 2016

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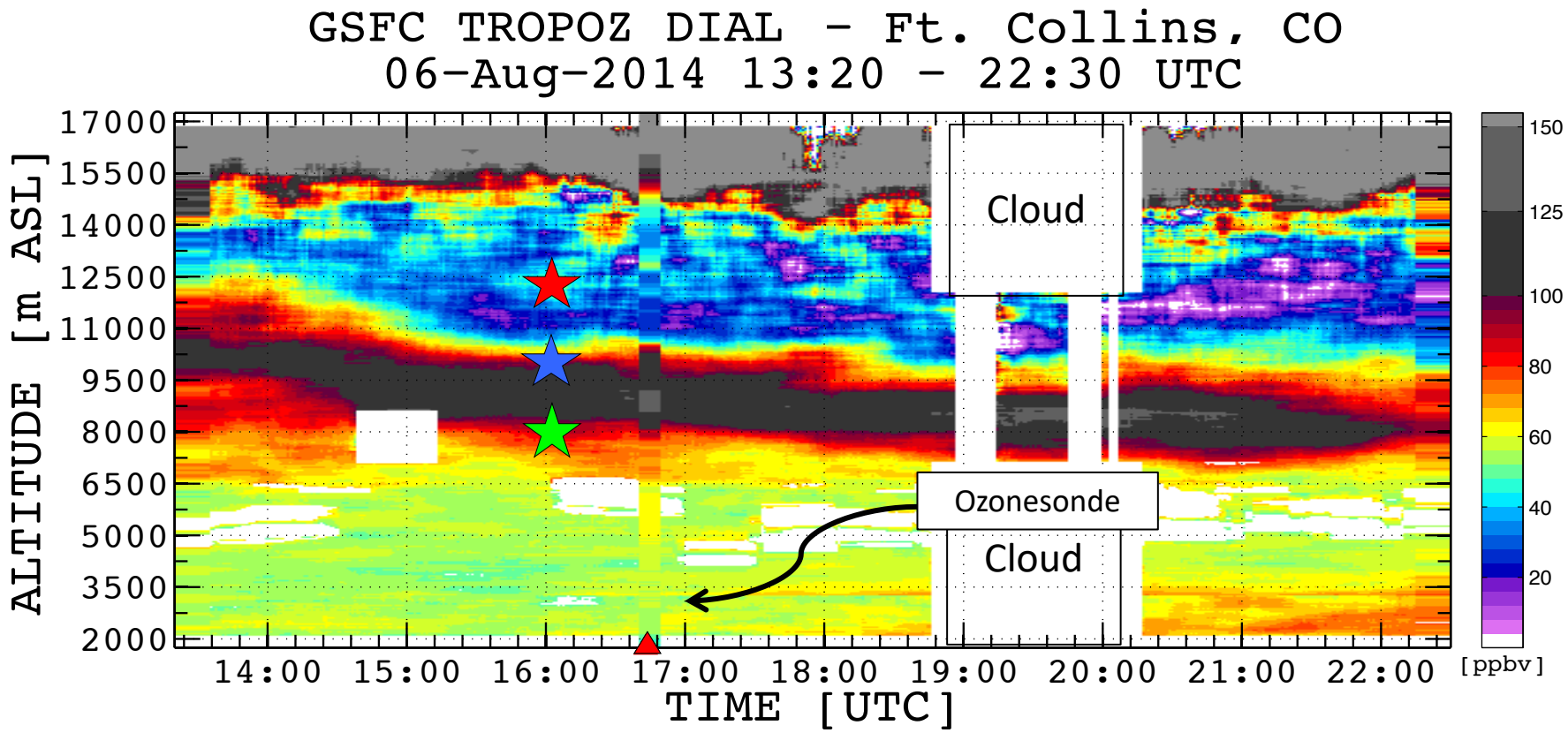
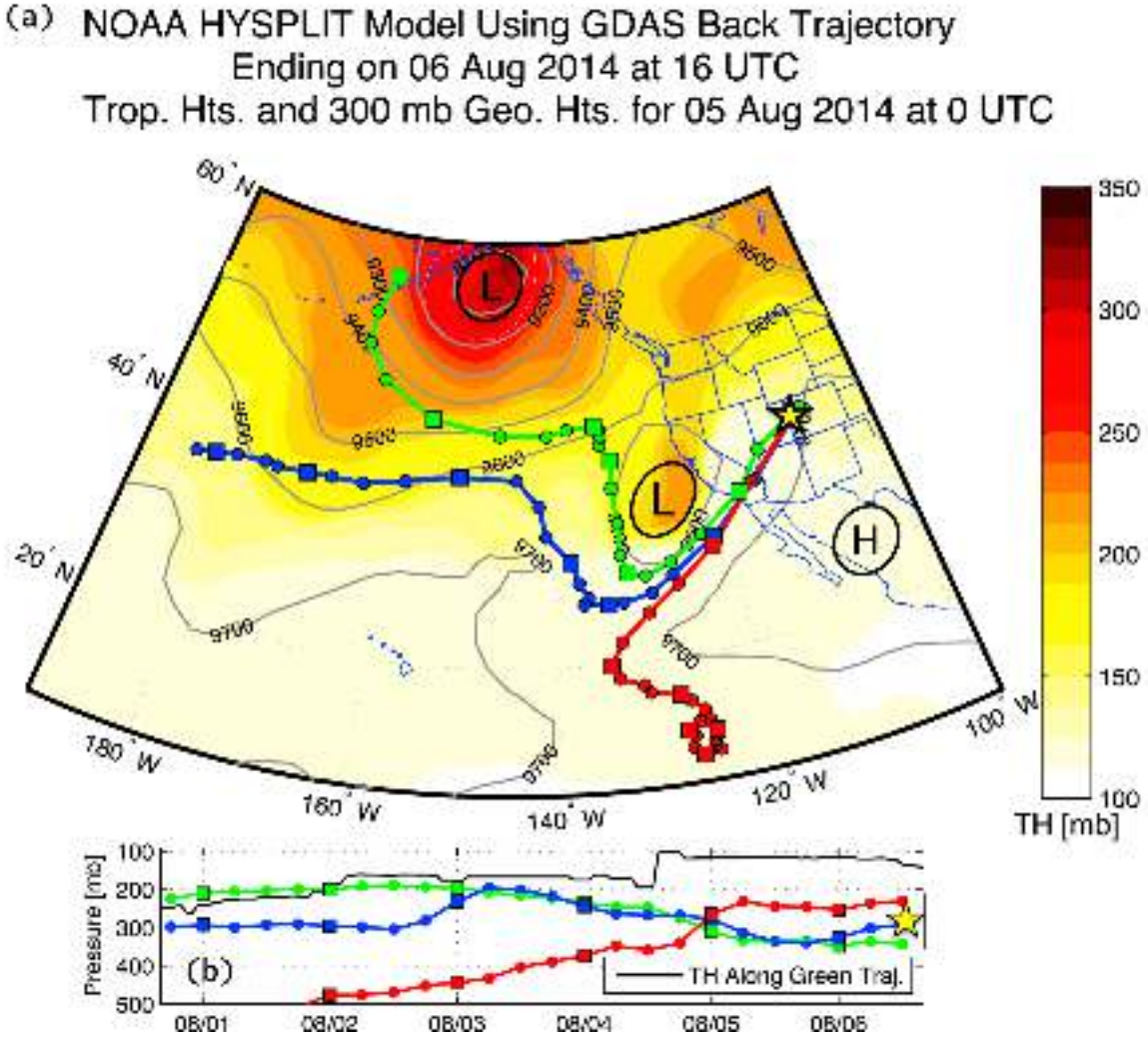
Strat. Trop Exchange



- Stratospheric-Tropospheric Exchange (STE) brings high O_3 into the free troposphere

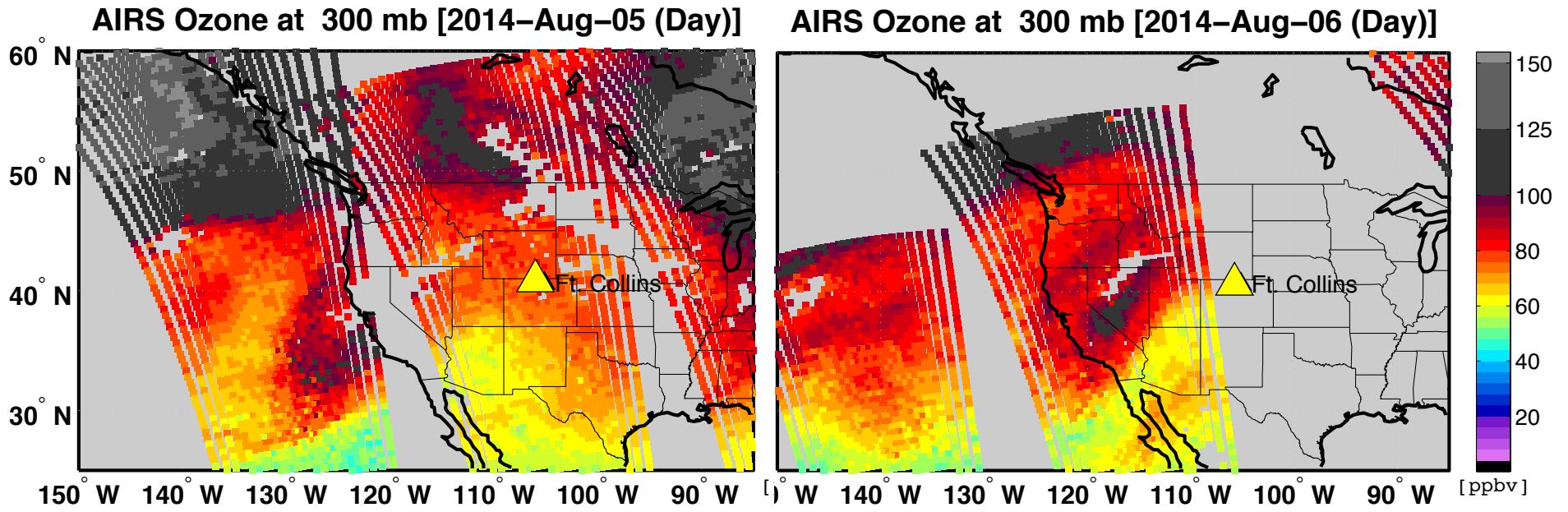
Sullivan, J. T., et al, "Characterizing the lifetime and occurrence of STE, JGR Atmos., 120, 2015

Strat. Trop Exchange



Sullivan, J. T., et al, "Characterizing the lifetime and occurrence of STE, JGR Atmos., 120, 2015

Strat. Trop Exchange



- Quantify contribution of stratospheric air residing within the free troposphere

Sullivan, J. T., et al, "Characterizing the lifetime and occurrence of STE, JGR Atmos., 120, 2015

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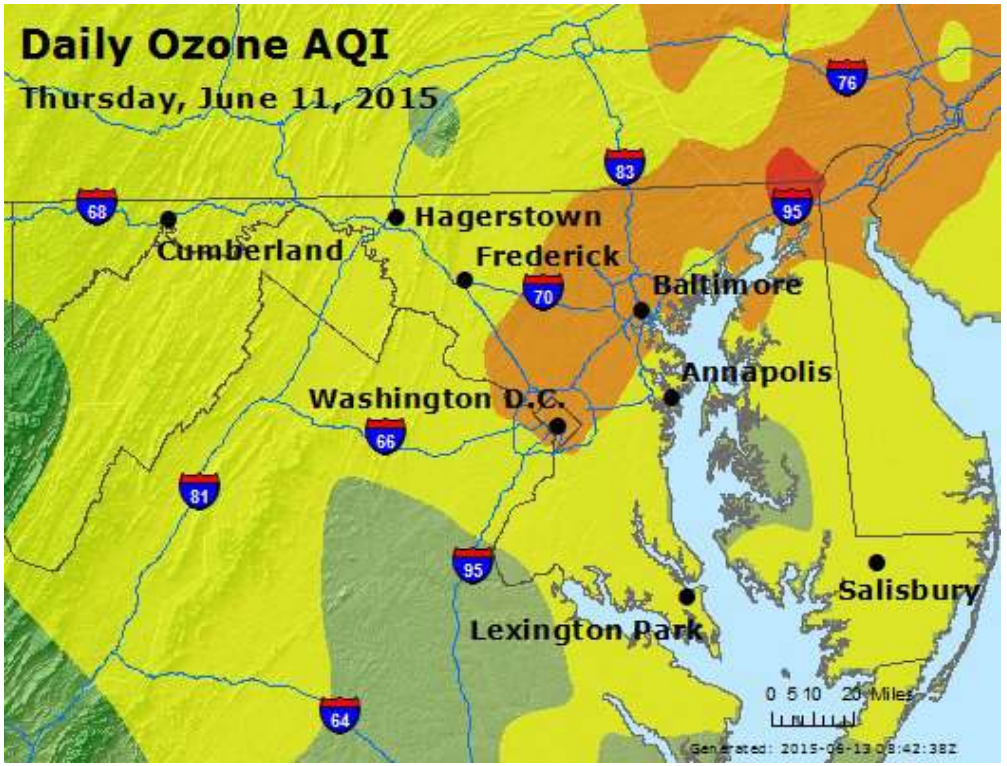
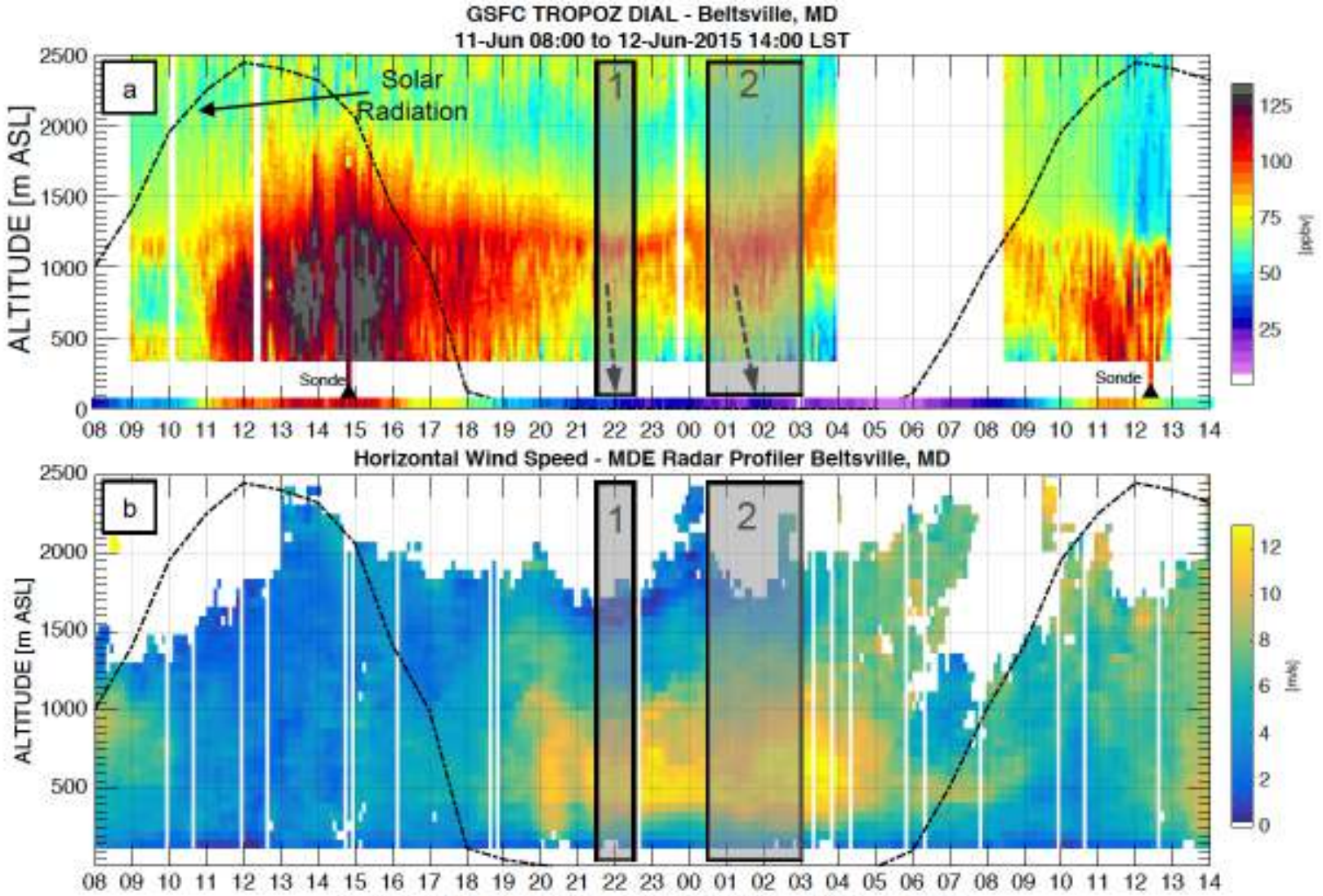
Maryland AQ Summary

- **UNHEALTHY** AQI at Fair Hill (northeast MD)
- **USG** at
  - All 3 DC monitors
  - 6 Maryland monitors
  - 70% of network >70ppb
- Event centered along I-95 corridor
- Worst air quality since 6/29/2012 (Derecho)



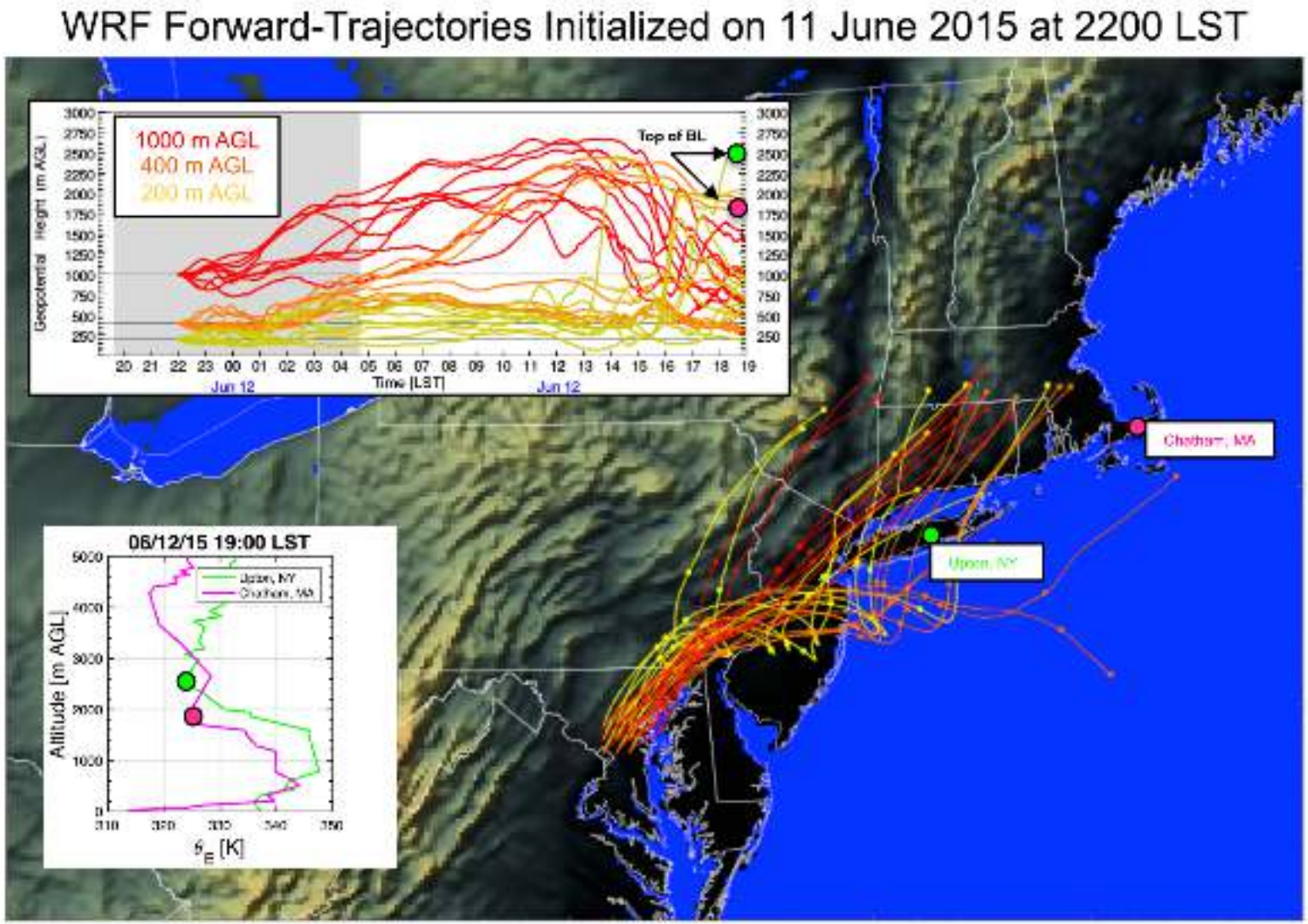
Data/figure courtesy Maryland Department of the Environment (MDE)

Low-Level Jets



Sullivan, J. T. et al., "Lidar of O_3 in a NLLJ: Regional implications." Atmos. Env., 2017

Low-Level Jets



Sullivan, J. T. et al., "Lidar of O_3 in a NLLJ: Regional implications." Atmos. Env., 2017

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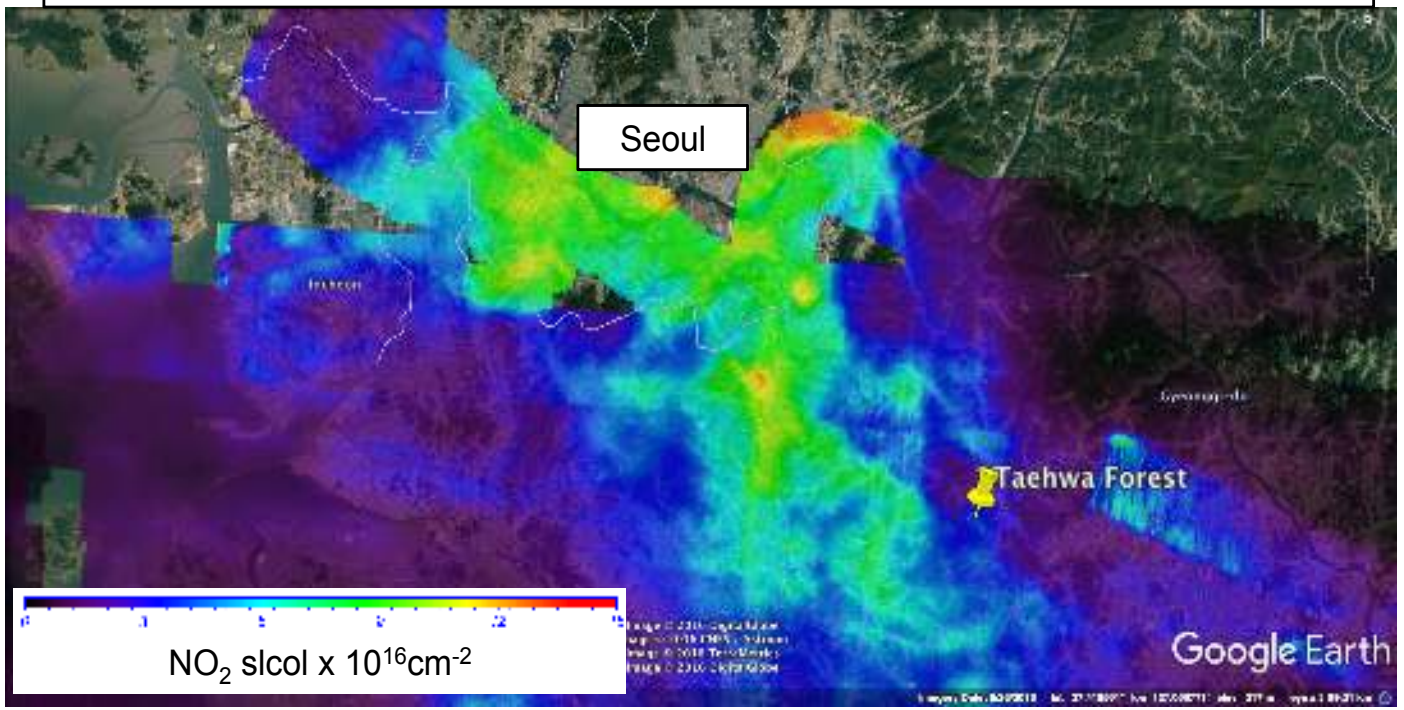
John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Sampling Seoul

NASA B-200 GEOTASO Flight 17 May 2016 14:00 – 16:00 KST

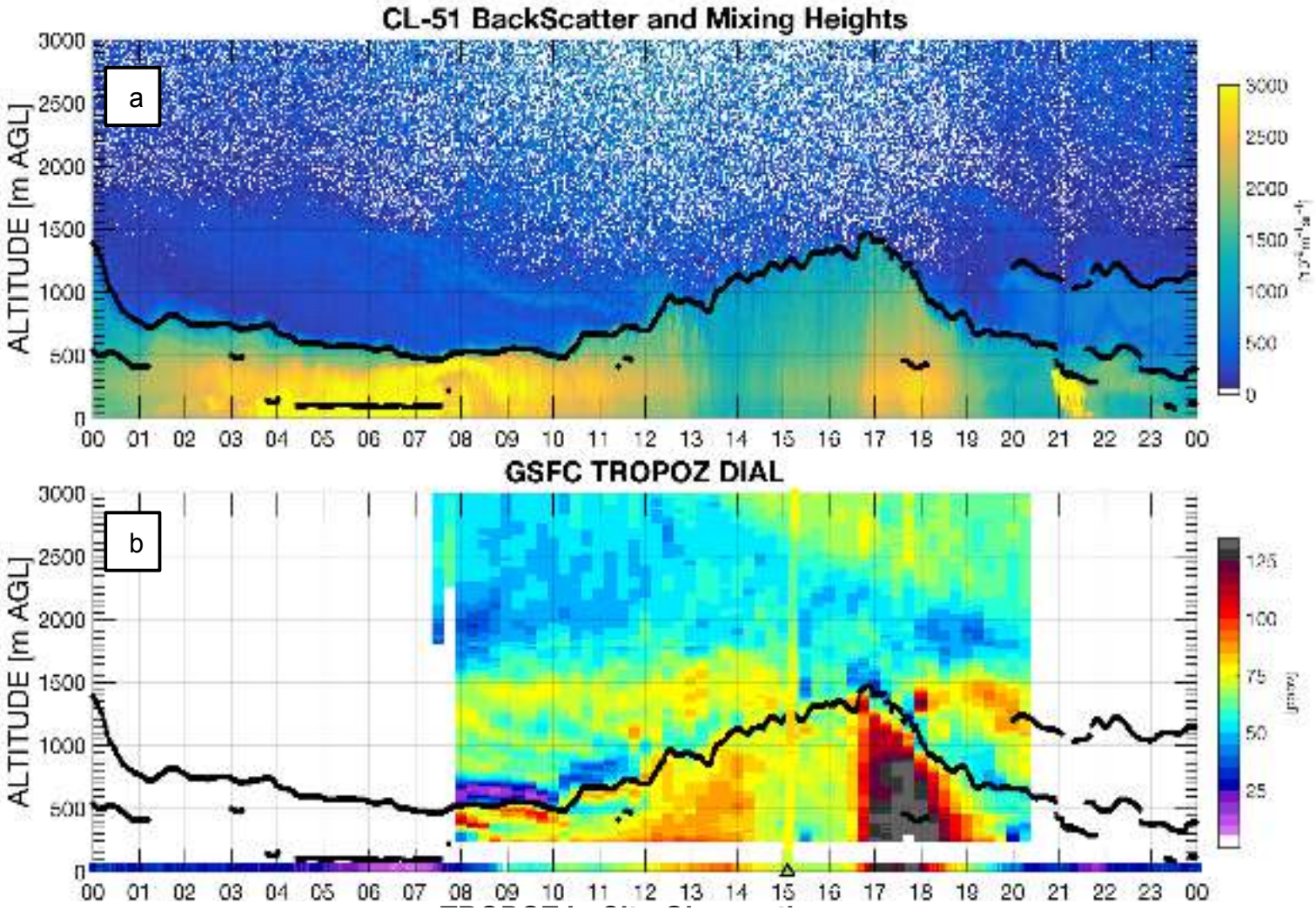


- GSFC lidar sampling Seoul plume during NASA KORUS-AQ. (Backdrop NO_2 slant col)

GeoTASO data courtesy Scott Janz (NASA/GSFC) and team

Sampling Seoul

TRF Remotely Sensed and In Situ Measurements 17 May 2016



Ceilometer data courtesy R. Long (EPA)

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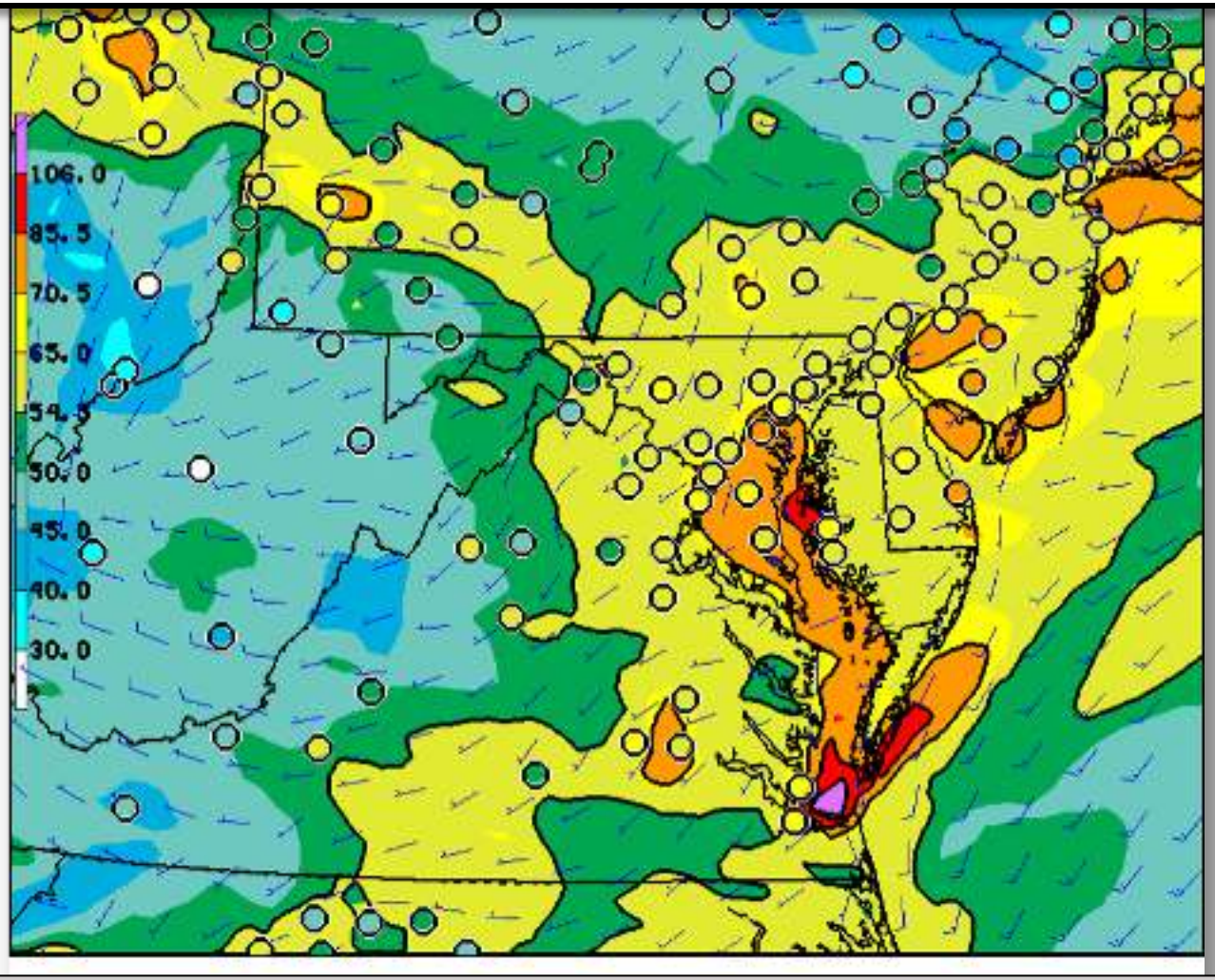
Background/Motivation

OWLETS
Ozone Water-Land Environmental Transition Study

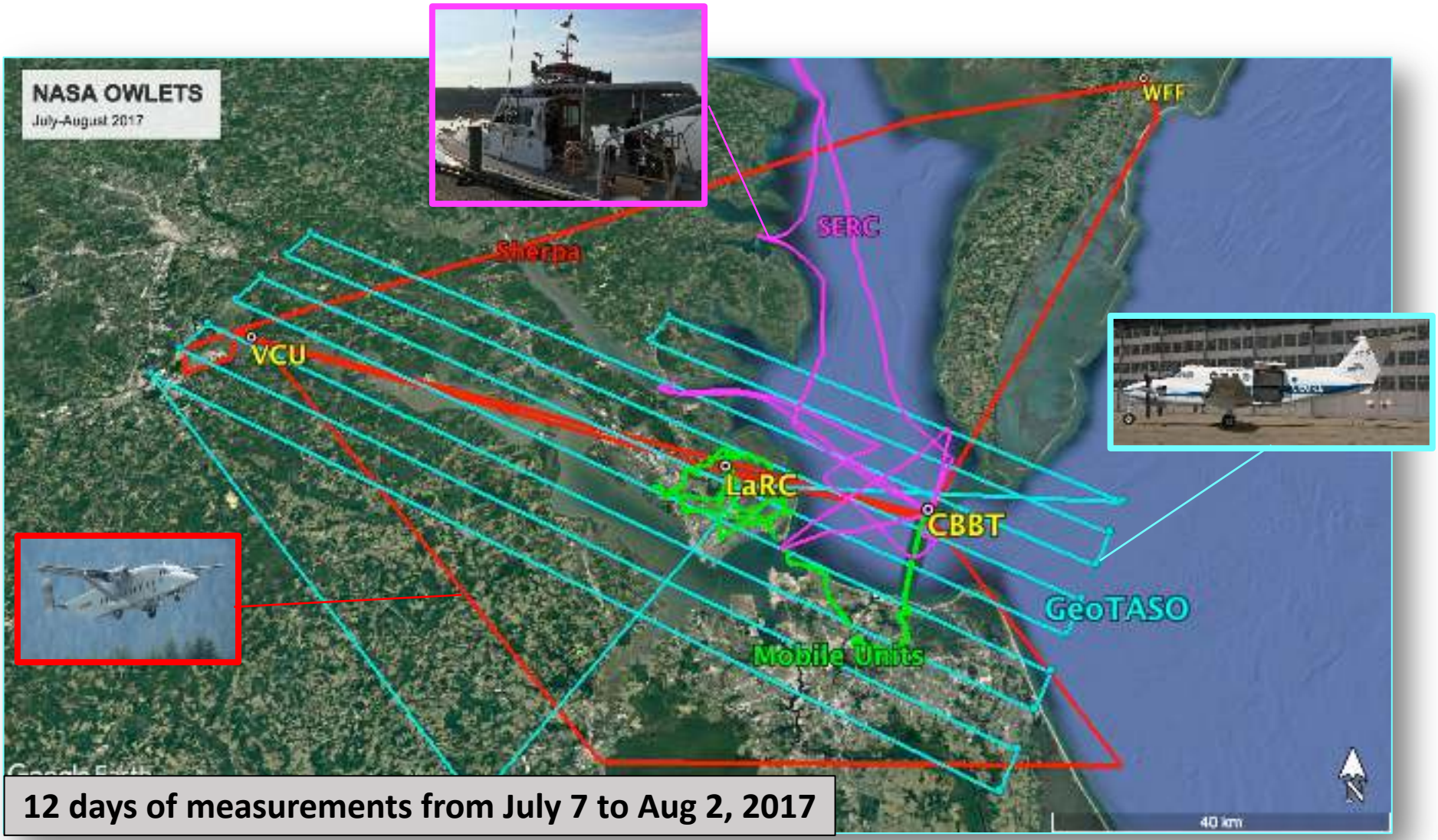
NOAA NAM 12 - CMAQ Ozone Forecast [20170721 14:00 LT]



Courtesy: http://www.emc.ncep.noaa.gov/mmb/aq/cmaq/web/html/

Sampling Strategy

OWLETS
Ozone Water-Land Environmental Transition Study

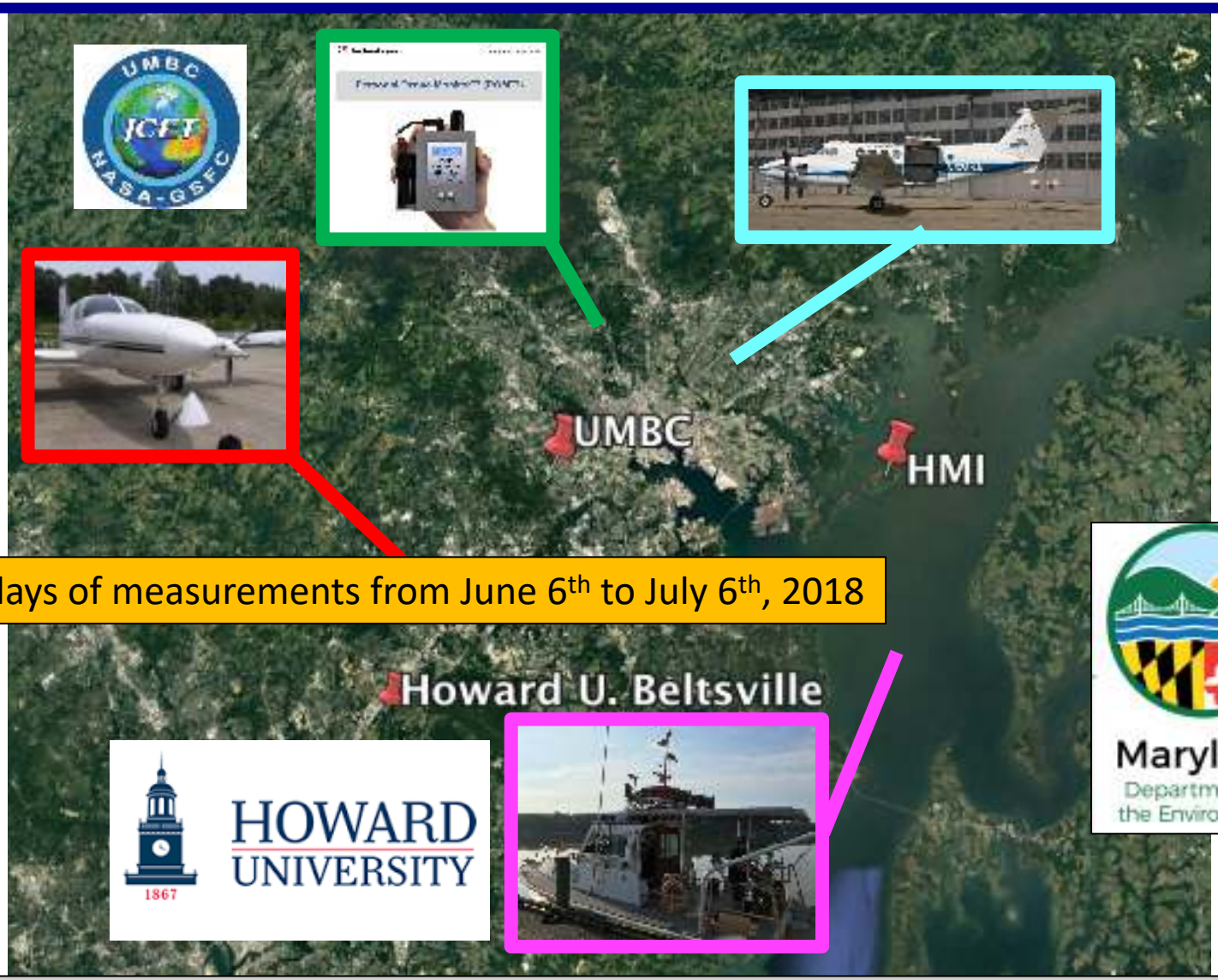


12 days of measurements from July 7 to Aug 2, 2017

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

OWLETS-2 Sampling

OWLETS
Ozone Water-Land Environmental Transition Study

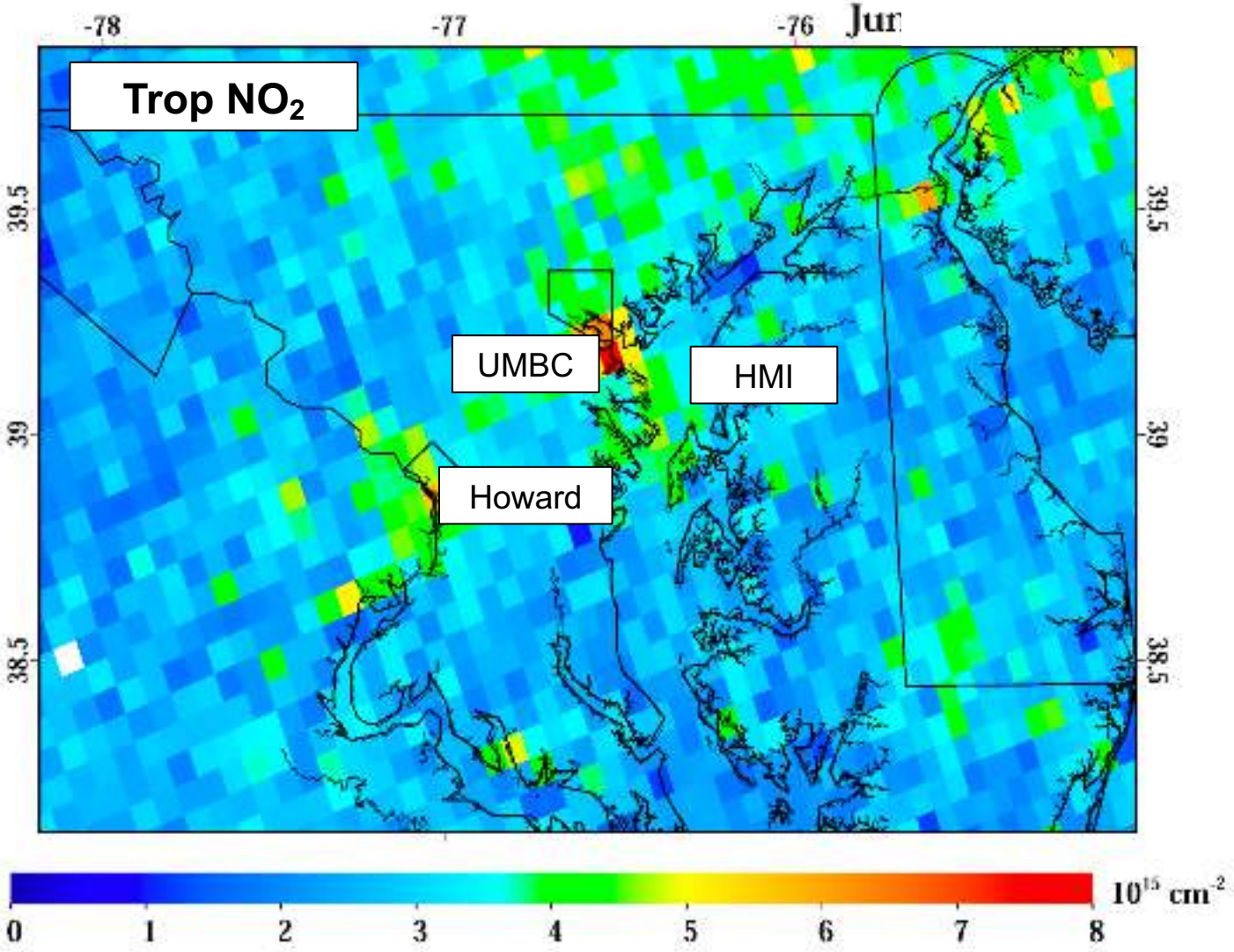


10 days of measurements from June 6th to July 6th, 2018

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

TROPOMI 06/30/2018, ~2p LT

OWLETS
Ozone Water-Land Environmental Transition Study



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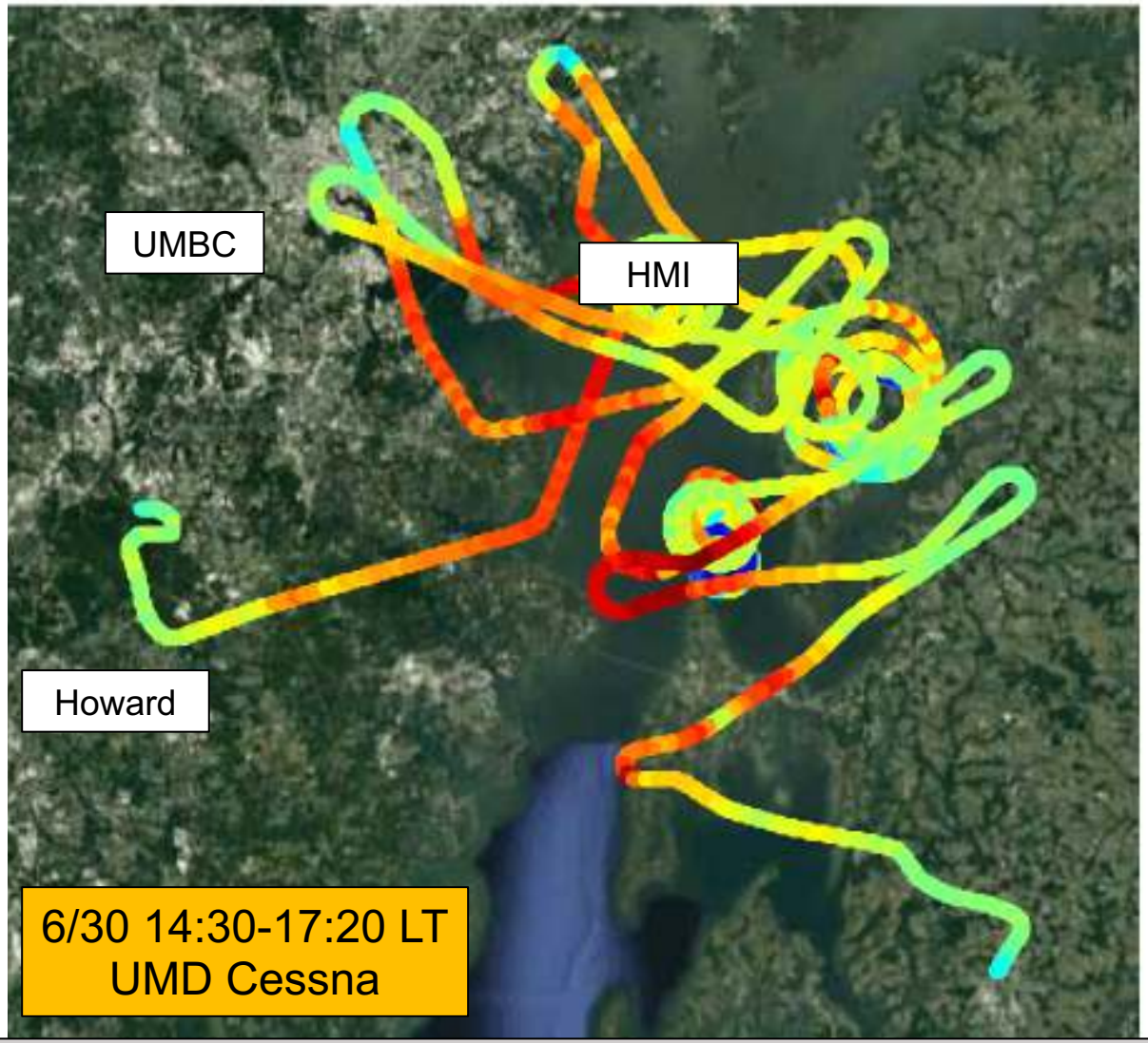
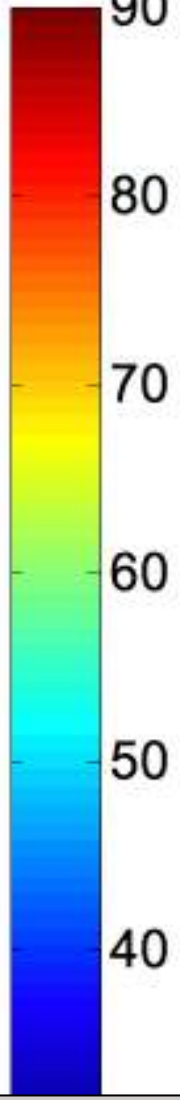
Direct Airborne Sampling

OWLETS
Ozone Water-Land Environmental Transition Study

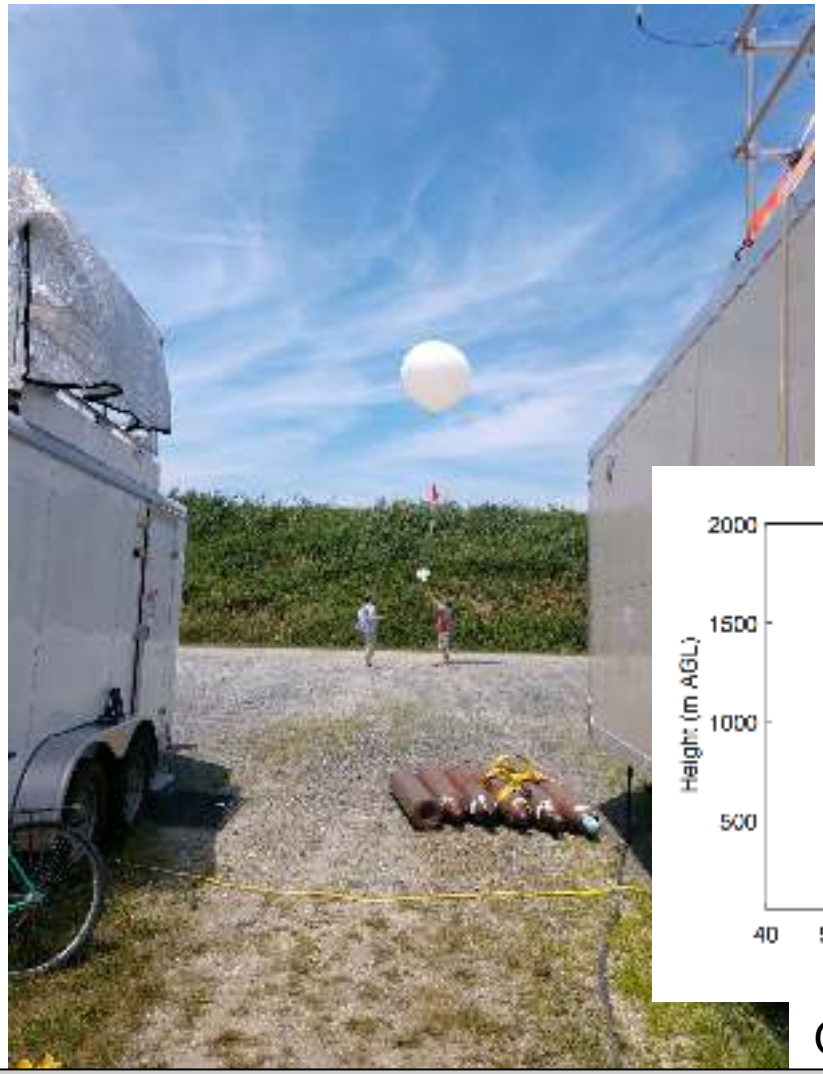




John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

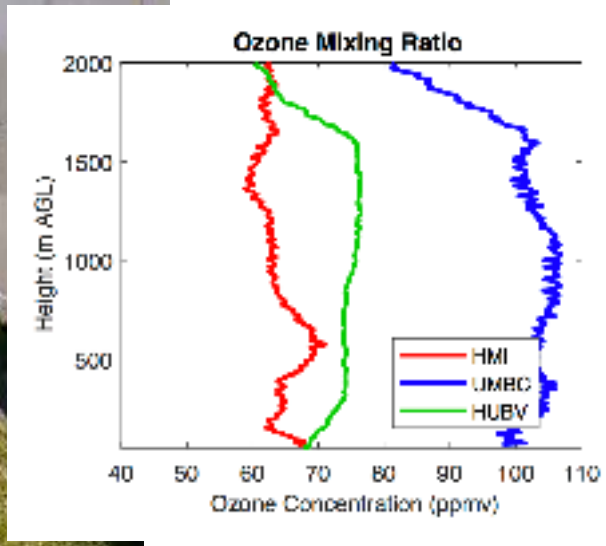
Balloon-borne Sampling

OWLETS
Ozone Water-Land Environmental Transition Study



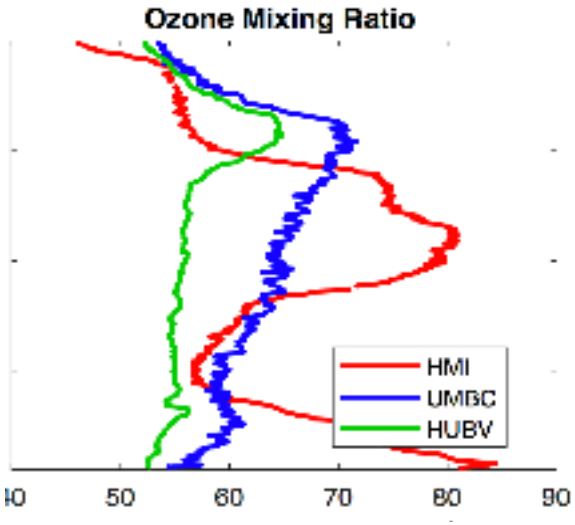
40 total launches between sites, mostly within 30 minutes of each other and 32 during satellite overpasses.
10 additional dual launches to investigate sonde performance

6/30 at 12:15 LT



Ozone [ppbv]

7/1 at 12:15 LT

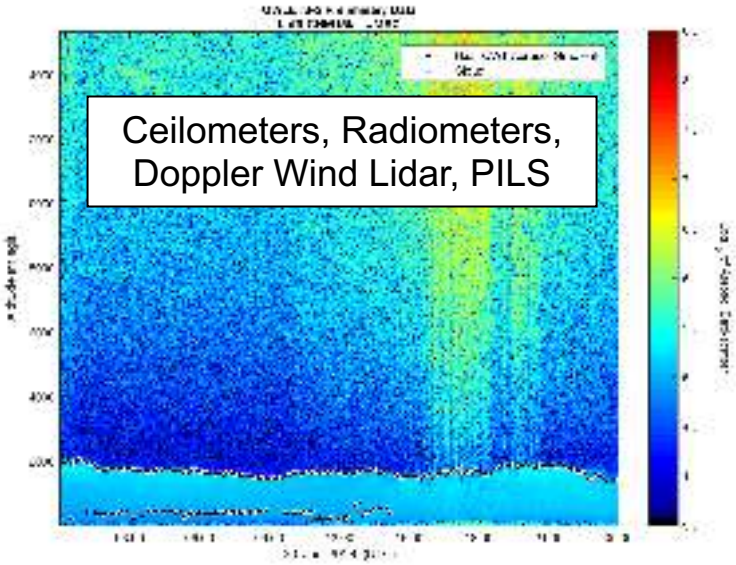


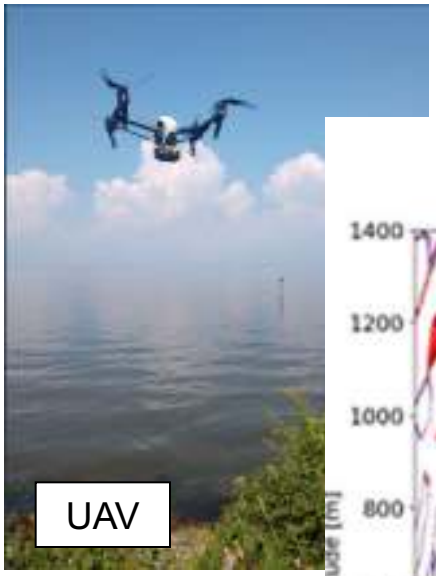
Ozone [ppbv]

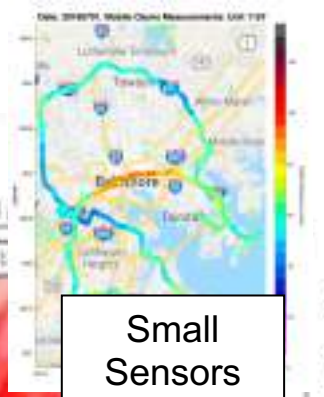
John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Additional Platforms

OWLETS
Ozone Water-Land Environmental Transition Study







Preliminary Data

Lidar Analyses

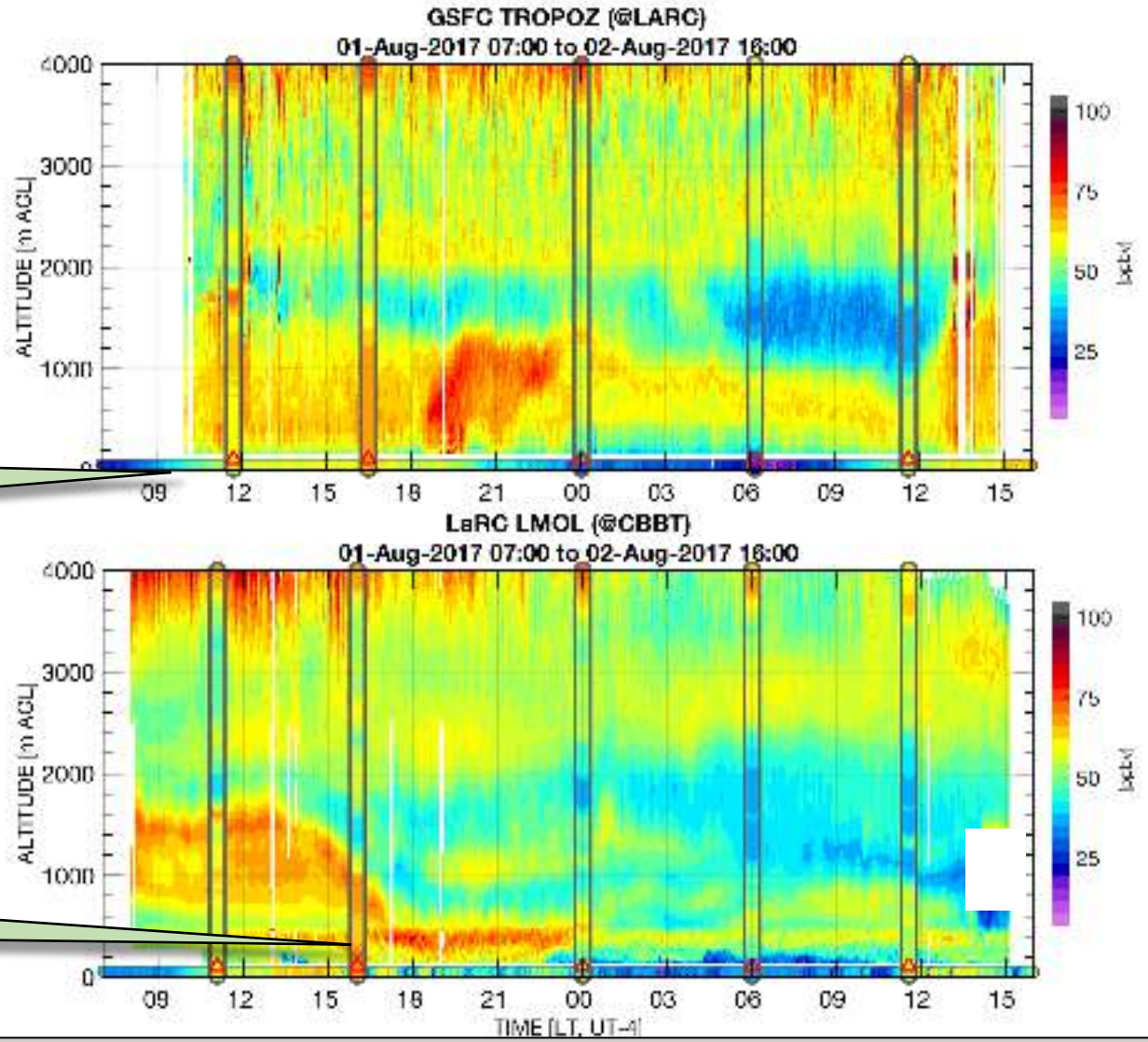
OWLETS
Ozone Water-Land Environmental Transition Study

On-Land

Surface O_3

Over-Water

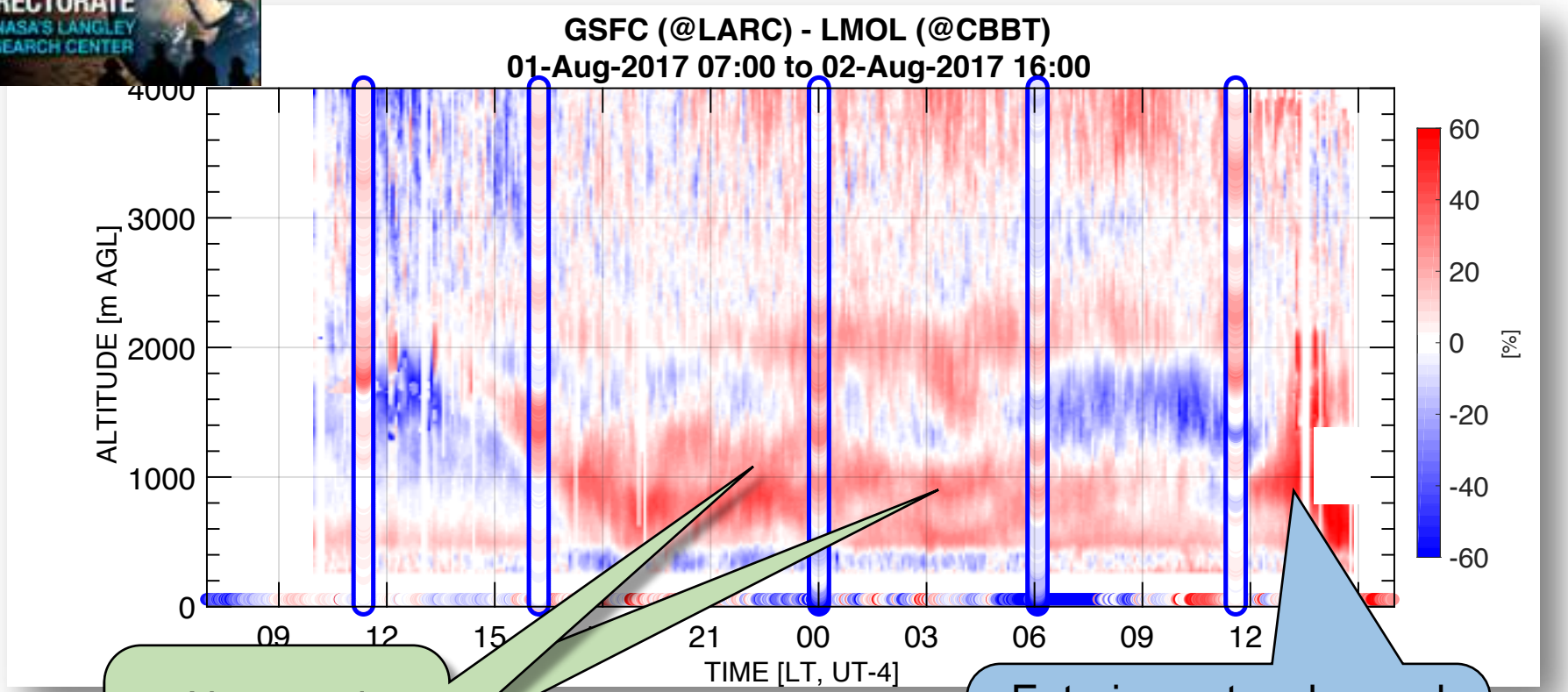
O_3-sonde



John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Lidar Differences

OWLETS
Ozone Water-Land Environmental Transition Study



Nocturnal Residual O_3 Layering

Entrainment, enhanced O_3 boundary layer as compared to over water

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Special thanks to NASA HQ/TCP, NASA TOLNet
For website quick look reports and archive:
www-air.larc.nasa.gov/missions/tolnet/
www-air.larc.nasa.gov/missions/owlets/

Come talk to me about the NPP Fellowship or Summer Program!
https://npp.usra.edu/opportunities/details/?ro=17768 ***Nov 1***
https://nasa.force.com/Mentors/s/my-projects?isdtp=p1 ***Nov 5/ Feb 5***

John Sullivan, NASA/GSFC *email: john.t.sullivan@nasa.gov*

Ozone Lidar Analysis Project
John Sullivan, Mentor

Ozone lidar data taken at Howard U. Beltsville campus during June 11-12, 2015 is in the Data folder as

- ***'groundbased_lidar.o3_nasa.gsfc003_hires_beltsville.md_20150610t000000z_20150611t000000z_001.hdf***
- ***groundbased_lidar.o3_nasa.gsfc003_hires_beltsville.md_20150611t000000z_20150612t000000z_001.hdf***

'ALTITUDE.INSTRUMENT' – Site altitude
'DATETIME' - Date Vector in UTC
'INTEGRATION.TIME' – 5 minutes
'ALTITUDE' – 1-D vector array of altitudes ASL (15m range bins)
'O3.MIXING.RATIO.VOLUME_DERIVED'– Ozone Data (ppmv, need to change to ppbv)

Other vectors – Ozone in number density, standard uncertainty, vertical resolution, meta data,
Details can be found: https://www-air.larc.nasa.gov/missions/TOLNet/docs/TOLNet_Format_ProfileData_V1.pdf

Hourly MDE surface data during the month of June at the site are also in the folder as

- ***'Surface_Species_HUBV_June_2015.csv'.***

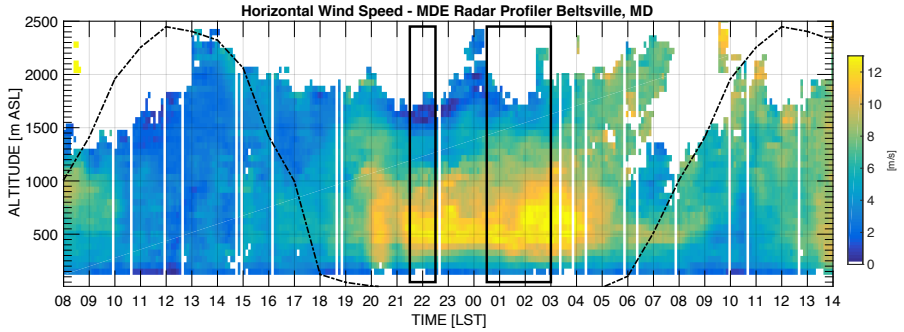
a. Read in the ozone lidar data and make a 'curtain' plot (i.e. x – time, y – altitude, z – ozone) of the data.

b. Read in the surface data and make a time series for June 11-12 of surface O3, NOx, NOy, and PM values.

c. After looking at the plot in a), choose two altitudes to make a line plot (i.e. x – time, y – ozone) of ozone values that represent the PBL and the free troposphere.
    i. Compare these with the surface ozone. Comment on why you chose these altitudes and what you could infer from the ozone lidar plot to help with this. Also comment on any discrepancies in data comparisons and if they may be attributed to local meteorology/dynamics, chemistry, or potentially an instrument artifact.

d. In order to connect this to a regional perspective, below is a plot of the wind profiler taken at Howard Beltsville wind speed (Connect this back to your wind profiler lesson with Dr. Demoz). What features in the ozone

curtain plot from a) correlate or anti-correlate with the nocturnal wind speed maxima?



e. Finally, below is a plot of surface ozone values on June 11 and 12 for the Northeast U.S. Comment on these ozone transport trends within the PBL and how the ozone lidar data is valuable for understanding the vertical extent of ozone.