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RPPR Final Report
as of 21-Sep-2018

Agency Code:

Proposal Number: 68864CHREP **Agreement Number: W911NF-16-1-0497**

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Report Date: 31-Jul-2018 Date Received: 30-Jul-2018
Final Report for Period Beginning 01-Sep-2016 and Ending 30-Apr-2018

Title: Enhancement of Capabilities in Education and Research Using Lidar and Other Techniques for Environmental Measurements

Begin Performance Period: 01-Sep-2016 **End Performance Period:** 30-Apr-2018
Report Term: 0-Other

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STEM Degrees: 2 **STEM Participants:** 4

Major Goals: The major goals of this work were to develop enhancements of capabilities in education and research using lidar and other techniques for environmental measurements through the procurement and implementation of a number of lidar and supporting instruments. The centerpiece is the addition of an optical parametric oscillator (OPO) to our existing large lidar that allows the measurement of a number of atmospheric gas profiles such as ozone, sulfur dioxide, nitrogen and nitrogen dioxide. A nine-channel sun tracking-photometer for column measurements of aerosol and water vapor was procured and implemented. Two balloon systems were added for profiling temperature, water vapor, pressure, and winds along with ozone. Another instrument added was the ozone measuring spectrometer Pandora. Finally, a small lidar for atmospheric planetary boundary height and water vapor measurements is being completed. Ultimately, the above have enhanced Hampton University's Atmospheric Sciences Department development of a suite of atmospheric remote-sensing and in-situ instruments for an improved understanding of atmospheric processes and composition within the boundary layer and free troposphere over Hampton. Lastly, new Thesis (MS) and Dissertation (PhD) research will result.

Accomplishments: The center piece of this effort is the development of a new lidar using an Optical Parametric Oscillator (OPO), and a pointing system for a small rugged scanning lidar. The new OPO system has been integrated into our existing 48-inch diameter receiving telescope lidar system that has been operational for a number of years, and produces routine ozone profiles. These profiles are being compared with our ozone balloon instrument purchased under this BAA funding. In addition, satellite measurements of ozone are being used to compare with our OPO lidar measurements. Examples are ozone profile data obtained with the Microwave Limb Sounder (MLS), a NASA instrument flying aboard the Aura satellite, and the Cross-track Infrared Sounder (CrIS) flying aboard Joint Polar Satellite System-1 satellite. The Pandora system, a ground-based ozone-measuring spectrometer, has not been delivered yet, but will be used for routine ozone comparisons. Our new pointing platform for our small portable tropospheric two-laser lidar development is nearly complete. The small scanning lidar will be used for tropospheric measurements of water vapor, aerosols and clouds with an elevation and azimuthal pointing capability.

These are complemented by supporting instruments and optical components purchased under this BAA, which include a 9-channel sun-photometer for column aerosol and water vapor data, and radiosonde and ozonesonde balloon systems for atmospheric profiling of ozone, wind, temperature, pressure and water vapor. The photometer is an automatic sun-tracking spectral radiometer that has allowed us to become a member of an international Aerosol RObotic NETwork (AERONET) measuring aerosol optical and physical parameters 24-7. The OPO laser is capable of producing laser outputs at wavelengths between 190 and 2200 nm. Therefore, many atmospheric gaseous components of the lower atmosphere can be retrieved and profiled including ozone, water vapor, SO2 and NO2.

Training Opportunities: Undergraduate and graduate students have been able to use the new balloon systems during our ozone inter-comparisons. They have also made presentations on these data to our Wednesday seminar series. In addition, graduate students have been involved in data comparison studies on ozone and aerosols using the new equipment plus satellite data, plus studies involving the tracking of stratospheric aerosol from distant volcanic eruptions. Additionally, they expanded their training in passive remote sensing, collection and use of external auxiliary data for calibration and validation, and simultaneous multiple-wavelength retrievals to enlarge the array of measured gases and aerosol properties in order to broaden awareness of the ambient atmospheric environment. They also prepared and participated in balloon launches to obtain temperature, winds and water vapor profiles on October 9, 2017. Lastly, students used lidar data to experience the effects of a partial solar eclipse on mixing in the planetary boundary layer.
Both graduate and undergraduate students have benefitted significantly with hands-on and classroom learning experiences operating and working with these new data, increasing their skill sets greatly.

Results Dissemination: The results shared included a presentation of the volcanic lidar data at a lidar conference and the balloon ozone data results was shared with the Maryland DEQ summer study participants on lower tropospheric ozone (OWLETS).

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Steven Buckner
Person Months Worked: 6.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Liqiao Lei
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Staff Scientist (doctoral level)
Participant: Jia Su
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

RPPR Final Report
as of 21-Sep-2018

Participant Type: Staff Scientist (doctoral level)
Participant: Michael Timothy Hill
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
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National Academy Member: N
Other Collaborators:

Participant Type: PD/PI
Participant: Michael Patrick McCormick
Person Months Worked: 2.00 **Funding Support:**
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Authors: Liqiao Liqiao, Michael P. McCormick, John Anderson
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Final Technical Progress Report

1 September 2016 through 30 April 2018
under the
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Army Research Office (ARO) and the Assistant Secretary of Defense for Research and Engineering (Research Directorate/Basic Research Office)

Enhancement of Capabilities in Education and Research Using Lidar and Other Techniques for Environmental Measurements

Proposal number: 68864-CH-REP
Agreement number: W911NF-16-1-0497
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Table of Contents

Abstract

US Army 2016 DOD HBCU/MI funding has allowed HU to develop significant enhancements to its atmospheric measurement capabilities, educational research opportunities, and overall research capacity at Hampton University. The center-piece of this effort is the development of a new lidar using an Optical Parametric Oscillator (OPO), and a pointing system for a small rugged scanning lidar. These are complemented by supporting instruments and optical components purchased under this BAA, which include a 9-channel sun-photometer for column aerosol and water vapor data, and radiosonde and ozonesonde balloon systems for atmospheric profiling of ozone, wind, temperature, pressure and water vapor. The photometer is an automatic sun-tracking spectral radiometer that has allowed us to become a member of an international Aerosol RObotic NETwork (AERONET) measuring aerosol optical and physical parameters 24-7. The OPO laser is capable of producing laser outputs at wavelengths between 190 and 2200 nm. Therefore, many atmospheric gaseous components of the lower atmosphere can be retrieved and profiled including ozone, water vapor, SO_2 and NO_2. The OPO system was integrated into our existing 48-inch diameter receiving telescope lidar system that has been operational for a number of years. The small scanning lidar will be used for tropospheric measurements of water vapor, aerosols and clouds with an elevation and azimuthal pointing capability. We routinely use multi-wavelength elastic scattering for characterizing aerosols and clouds, Vibrational Raman scattering for water vapor measurements and Rotational Raman scattering for our lidar temperature measurements. The tunable OPO lidar allows us to make differential absorption lidar (DIAL) measurements. The use of these multi-wavelength active lidar instruments taken together with the passive sun photometer and balloon in situ instruments greatly expand the skill sets of our students, as well as, enhance the capacity of our university. Examples of research studies will be described.

Product	HU Instrumentation							
	Met Sonde (0-30km)	O3 Sonde (0-30km)	Cimel Photometer (column, 9 λ s)	48" Mie-Raman OPO DIAL (0-30km)	48"Mie-Raman lidar (0-30km)	Doppler lidar (0-5km)	Scanning lidar (0-5km)	Pandora Photometer
PBL Height	X	X		X	X	X	X	
Aerosol Optical Depth			X	X	X			
Column Size Distributions, Single Scatter Albedo, Assymetry Factor, and Precipitable Water			X					
O3 Profile		X		X				
Column O3, NO2, and SO2								X
Aerosol Profile				X	X		X	
Cloud Heights and Properties				X	X		X	
H_2O Profile/RH	X	X		X	X		X	
Temperature Profile	X	X		X	X			
Wind Profile	X	X				X		
Various Gases (SO_2, NO_2, CH_4, etc., λ= 190 nm-2.2 µm				X				

Table 1. *Instruments purchased, enhanced (basic lidar) or ordered (Pandora) under DoD BAA Funding. The Doppler lidar is on loan from the ARL.*

Executive Summary

A Mie-Raman-Differential Absorption Lidar (MRDIAL) system was developed to measure an increase of ozone, better characterize aerosols, and investigate optical and physical properties of the boundary layer over HU. The system was build on our present capabilities using the existing 48-inch lidar. Added to our Nd:YAG 3-wavelength laser will be one optical parametric oscillator (OPO) tunable lasers, a new beam separation unit utilizing a tunable diffraction grating, additional channels to our Licel multi-wavelength data acquisition system, and some auxiliary optical components. Incorporating two tunable OPO lasers able to tune over a broad wavelength range and a tunable grating-based receiver system allows an instantaneous measurement to be made on and off an absorption feature of the gas of interest across the wavelengths 192 nm to 2750 nm. The lidar will be used to greatly expand the capabilities of our 48-inch lidar system to conduct basic research of the lower atmosphere and to significantly expand the educational and training opportunities for current and future undergraduate and graduate students in multi-wavelength lidar remote-sensing, atmospheric retrievals, and generally in all STEM areas. A multi-wavelength Cimel sun photometer was purchased to measure aerosol optical depths, aerosol physical properties, and derives gaseous column concentrations. The system contains an automatic sun-tracking photometer with filters for nine wavelengths. Our center and academic department will use the instrument to complement the measurements from its existing 48-inch lidar system in order to improve aerosol extinction estimates, obtain column aerosol size distributions, and enhance via column water vapor estimates our Raman water vapor profile measurements. A rawinsonde system was purchased to obtain auxiliary meteorological data over the troposphere and especially in the boundary layer over HU. The system consists of a portable atmospheric sounding unit with an antenna and receiver assembly and a computer with custom data processing software. The instrument will be used to validate and complement the measurements from its existing 48-inch lidar and ARL wind lidar system to measure temperature, humidity, and wind velocity in the boundary layer. This will give the department the ability to train students in fundamental meteorological research with an in-situ instrument and provide environmental context and validation for other remote-sensing observations.

Section I: The completion of tasks

1. <u>HU multi-wavelength tunable Mie-Raman-Differential Absorption lidar</u>

Under funding from the US Army's Contract W911NF-16-1-0497, HU has developed a multi-wavelength tunable Mie-Raman-Differential Absorption (MRDA) lidar. New components have been integrated to form a first generation MRDA lidar. Figure 1.1 shows a schematic of the new lidar purchased under the BAA contract, based on our 48-inch existing lidar. Table 1. shows measurement accuracies expected for various gaseous measurements. The light source for the system includes a Continuum Powerlite 8020 Nd:YAG laser (part of our pre-existing lidar), a Continuum Powerlite DLS 8000 pump laser, and a Continuum Horizon II tunable optical parametric oscillator (OPO). OPO lasers enable researchers to optimize (tune) the wavelength choices and, in that sense, open up new possibilities for many gaseous and particulate measurements. Its optical design delivers high output power over an extensive tuning range (192-2750 nm). The final HU system will be nearly automated when completed with precision scanning for true hands-free operation. The Horizon II system is a very robust system with the highest conversion efficiency available from any mid-band OPO; it has outstanding beam quality, excellent beam pointing stability and the option for wavelength access extended into the vacuum ultraviolet. With crystals and Pellin Broca prisms mounted directly to ultra-high resolution stepper motors, the Horizon has optimal stability and tuning reproducibility at all wavelengths. The Powerlite DLS 8000 laser is the next generation in high-energy YAG laser design. It combines the performance and reliability of the Powerlite laser family with modern digital power supply and control architecture. The differential absorption measurements are obtained by scanning on and off, an atmospheric absorption feature at wavelengths (λ_{on} and λ_{off}). A steering mirror whose axis is aligned with a receiving telescope axis directs these laser outputs into the atmosphere. The laser backscatter is collected by the existing HU 48-inch telescope and split into specific wavelength bands by the beam separation unit shown in Figure 1.1. A new beam separation unit is based on the existing design, but adds two blazed grating systems (Newport Corporation), for dispersion of the return backscatter to various channels shown in Figure 1.3. Using a grating system makes a beam-splitting system simple, compact, and easy to change or add other spectral channels for measurements. Shown are five(5) wavelengths of the laser returns (288.38, 299.50, 300.00, 395.60 and 396.82 nm) which are focused by concave mirrors to five Hamamatsu PMTs and recorded by a Licel data-collecting system. One Ocean spectrometer and optical gratings shown in Figure 1.4 were purchased to calibrate the OPO laser system output wavelength. Table 1 shows the expected retrieved products and measurement capabilities. The OPOs and other new components were procured using funding from the DoD BAA. Ozone measurement capabilities have been completed as a first demonstration of our new capabilities. Figure 1.5 shows an ozone profile retrieved using the MRDA HU lidar. Figure 1.6 shows ozone profile measurements from 10:00 am to 8:00 pm EDT over HU. Figure 1.7 shows HU Lidar ozone results compared with the Microwave Limb Sounder (MLS) instrument aboard NASA's Aura satellite (measurements from MLS were about 600 km from the HU lidar and on the same day). Figure 1.8 shows a comparison of HU lidar results with the Cross-track infrared Sounder (CRiS), a Fourier transform spectrometer, that is flying aboard NASA's Joint Polar Satellite System spacecraft. The satellite measurements were approximately 50 km from the HU measurements.

Species and characteristics	SO_2	NO_2	O_3	Aerosol size distribution	Aerosol single-scattering albedo	Aerosol complex refractive index
Minimum detectable concentration (ppb)	10	25	6	N/A	N/A	N/A
Range resolution (m)	7.5	7.5	7.5	7.5	7.5	7.5
Maximum detectable range (km)	5	6	6	8	8	8

Table 1.1 *Expected products to be retrieved using the HU multi-wavelength tunable Mie-Raman-Differential Absorption lidar.*

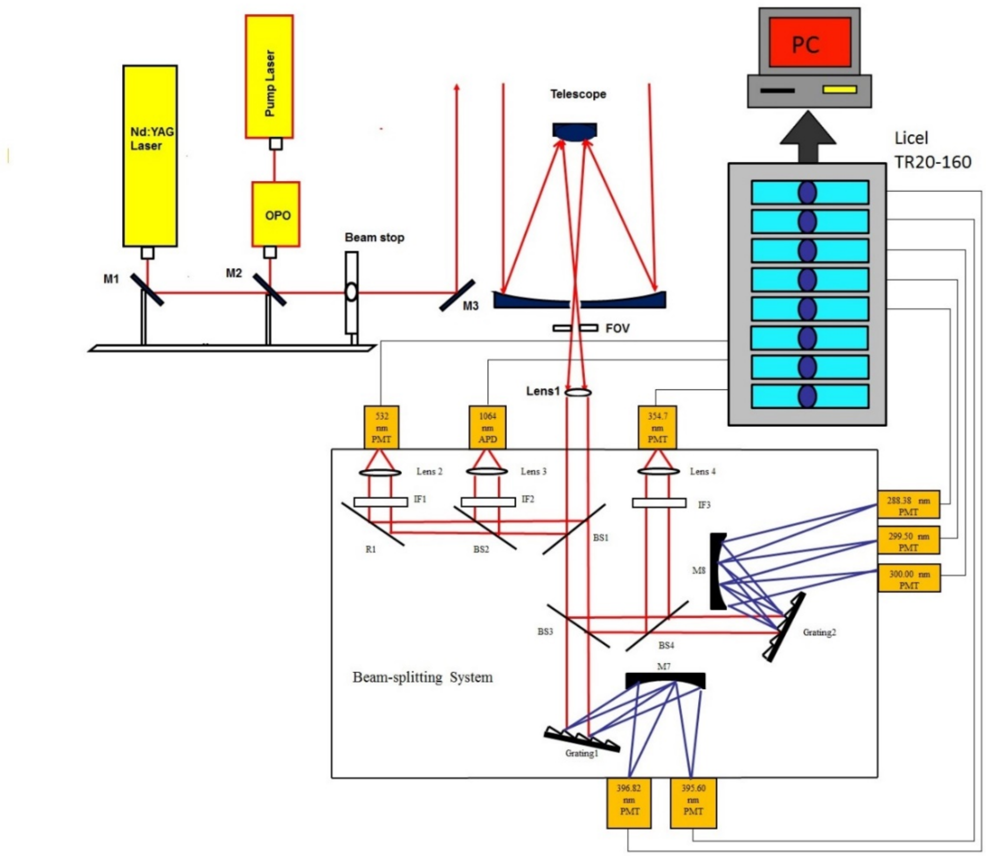

Figure 1.1 *Schematic of the HU tunable Mie-Raman-Differential Absorption lidar. It is built upon the existing 48-inch HU lidar and its technology developed over many years of experience and improvement. The receiver system utilizes the 48-inch primary diameter Cassegrainian-Configured telescope, eight receiver wavelength channels consisting of beam steering elements, optical filters, detectors and a bank of analog-to-digital converters for each channel are included. The A/D outputs are sent to a computer for further signal processing and storage.*

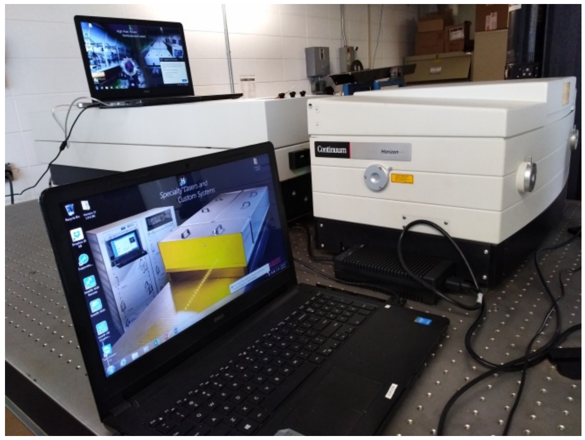

Figure 1.2 *OPO laser system*

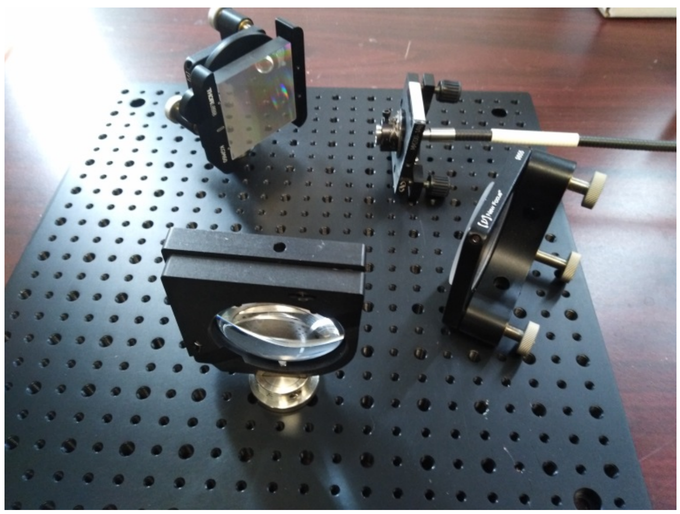

Figure 1.3 *Beam-splitting system based on gratings (not completed at this time)*

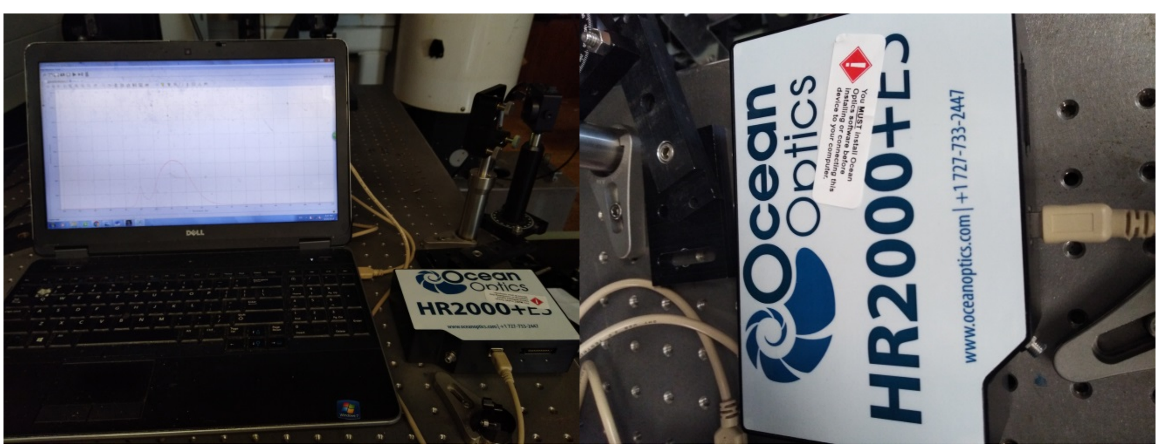

Figure 1.4 *Ocean spectrometer*

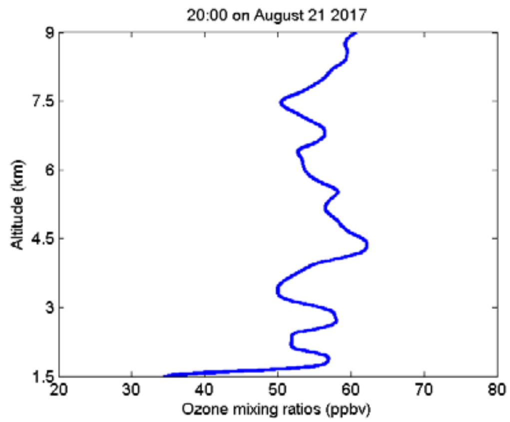

Figure 1.5 *Ozone profile*

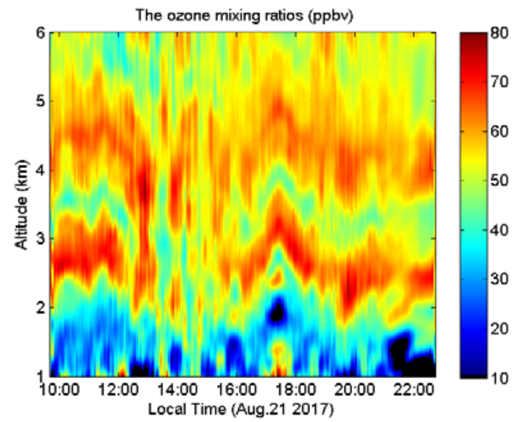

Figure 1.6 *Ozone variation from 10:00 to 22:00*

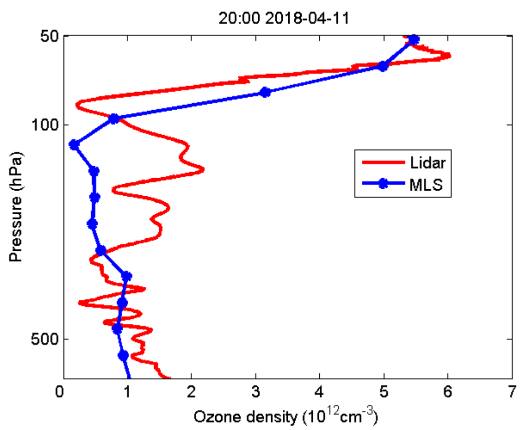

Figure 1.7 *HU Lidar results compared with the Microwave Limb Sounder (MLS). Separation of 600km.*

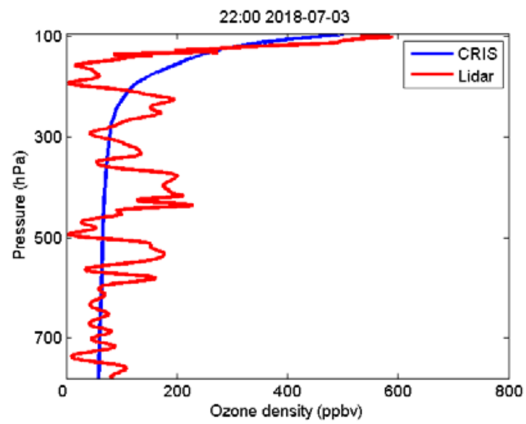

Figure 1.8 *HU Lidar results compared with the CRoss- track infrared Sounder (CRiS). Separation of 50 km.*

2. Sun photometer

The Cimel automatic sun-tracking photometer CE-318 TS-9 shown in Figure 2.1 was installed at HU in May, 2017. The CE 318 automatic sun tracking photometer has been designed and developed to be a very accurate sun photometer with all the qualities of a field instrument, including being motorized, portable, and autonomous (solar powered). Its main purpose is to measure sun and sky radiance in order to derive total column water vapor and aerosol properties using a combination of spectral filters and azimuth/zenith viewing controlled by a microprocessor. This instrument is the AERONET (Aerosol Robotic Network) standard. AERONET is a world-wide network of sun photometers consisting of institutions worldwide. The direct sun measurements are made within a 1.2° field-of-view at least every 15 minutes in nine spectral bands (340, 380, 440, 500, 675, 870, 940, 1020, and 1640 nm).

These are used to compute aerosol optical depth at each wavelength, except for the 940 nm channel, which is used for column water vapor data. Figure 2.2 shows (a) multi-wavelength aerosol optical depth (OD), (b) Angstrom exponents (440 nm-870 nm), (c) coarse and fine aerosol OD and (d) precipitable water.

Figure 2.1 Sun photometer at Hampton University.

Specifications	Value	
Sensor head	Irradiance precision	< 0.1%
	Half field of view	63°
	Smallest scattering angle (from the sun) for sky measurements	2°
	Spectral range	340 to 1640 nm standard (depending on sensor head model)
	Long term drift of single band filters' transmission rate	< 1%/year
Robot	Number of axes	2 axes : azimuthal and zenithal
	Angular scanning	Whole sky angular scanning:0°-360° in azimuthal angle, 0°-180° in zenithal angle
	Resolution/ tracking precision	0.003°
	Sun/Moon tracking accuracy (automatic active tracking)	0.01°
Power supply	Solar panel	5 W solar panel embedded in the protection enclosure of the control unit
	Main	Power adapter (110 - 240 V)
	Batteries	8 Ah sealed lead gel batteries set (to be placed outside of the control unit in the protection enclosure)
General		
	Infrastructure	Tripod, with protective enclosure
	Total weight (including tripod infrastructure)	38 kg

Table 2.1 Technical features of the CE 318

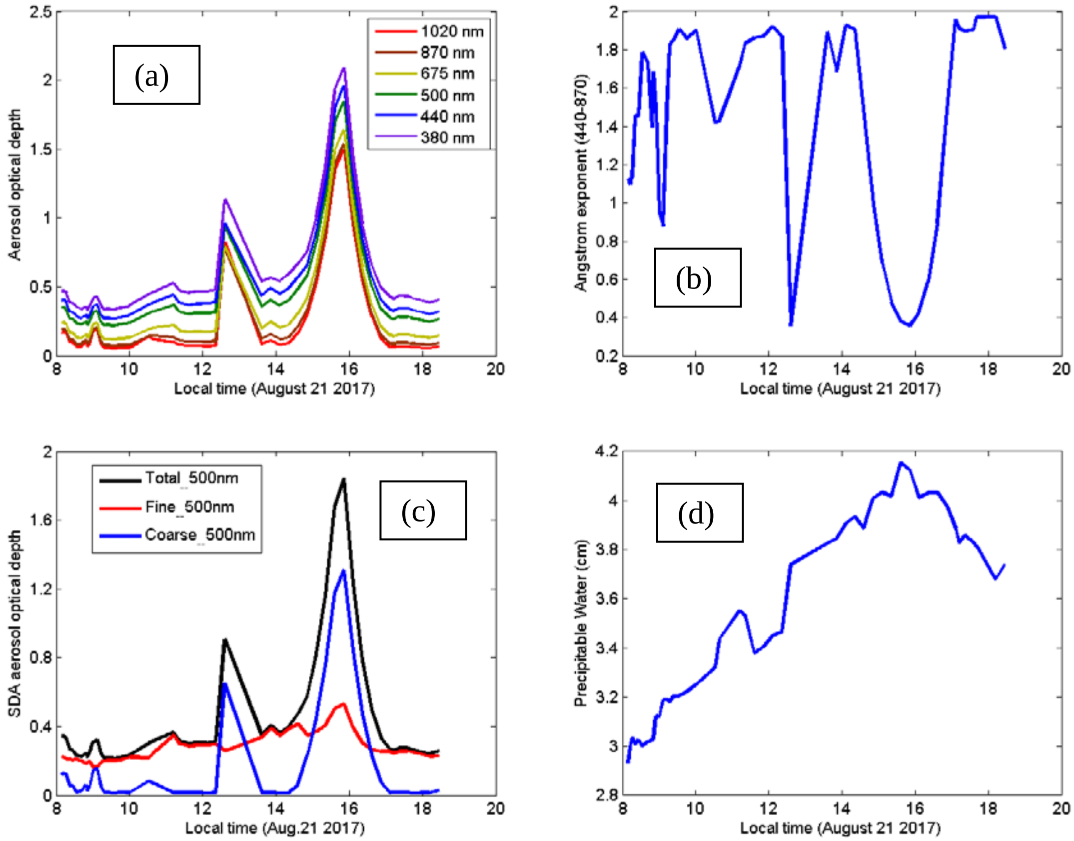

***Figure 2.2** shows (a) multi-wavelength aerosol optical depth (OD), (b) Angstrom exponents (440 nm-870 nm), (c) coarse and fine aerosol OD and (d) precipitable water on August 21 2017.*

3. Rawinsonde

The of iMet-3050A rawinsonde system (shown in Fig 3.1) is being used to calibrate and validate the measurements of temperature, humidity, wind velocity and mixing layer heights from our existing 48-inch lidar and Army Research Laboratory (ARL) wind lidar system occasionally located at HU on a non-continuous basis. Routine analysis of upper troposphere-lower stratosphere temperature and wind measurements using rawinsonde data can lead to a better understanding of seasonal and geographic variations in gravity wave activity and its spectral characteristics. Moreover, rawinsonde data can be utilized to investigate convection in relation to the mass flux and water vapor budget and troposphere-stratosphere transport. The rawinsonde provides an opportunity for strong student involvement in our research activities. The participation in research is helping students find connections between their class work and ongoing research activities. Also, learning science with hands-on laboratory and field experiences motivate students to continue their education and pursue advanced degrees in the atmospheric sciences. For example, our Atmospheric and Planetary Sciences (APS) Department graduate students launched a rawinsonde on September 29, 2017 (sunny day) and on October 9, 2017 (cloudy day). The launches were part of the APS 645 (Atmospheric Physics) course material covering atmospheric stability analysis. Students took the raw data and plotted it on a skew-t log-p diagram and contrasted the sunny day to the cloudy day rawinsonde data, applying stability principles taught in class. On the sunny day, the atmosphere was convectively stable whereas on the cloudy day, the atmosphere was convectively unstable. Figure 3.2 shows a picture of students preparing to launch a balloon for obtaining temperature, winds and water vapor profiles. Figure 3.3 shows results obtained from the launch on October 09, 2017. Figure 3.4 shows planetary boundary layer (PBL) heights retrieved from results of rawinsonde and lidar elastic backscatter (1064 nm) on October 09, 2017. In addition to our standard rawinsonde measurements, ozonesondes that are compatible with the iMet Rawinsonde System have been ordered, which are capable of making ozone profile measurements to 30 km. The ozone balloon system has been delivered and is in operation.

System Overview	
Operating Principle	Automatic GPS
DGPS	Standard
Frequency	400.15 – 406 MHz
Operating Mode	Mobile
Operating Environment	Rain Proof
System Architecture	Digital
Users Required	1 person
MTBF	> 2400 Hours
Useful Life	8 Years
Software	iMetOS-II

Operating Parameters	
Power	Via USB port from PC
Outside Equip Temp	- 20 to + 40 Deg C
Antenna	2.2 kg
Complete System	< 10 kg, including field case
Antenna Length	35 cm
Tripod	1.5 m, fully extended

Sounding Performance	
Max Slant Range	> 250 Km
Max Altitude	> 35 Km
Reports	WMO, BUFFR
Interfaces	Google Earth, RAOB
Ozone Capable	Standard

403 MHz Antenna	
Antenna Type	Quarter-Wave Monopole
Construction	Fiberglass/Aluminum
Polarization	Vertical
Impedance	50 Ohm
Gain	2 dBi
Radiation Pattern	Omnidirectional

403 MHz Receiver	
Type	Superheterodyne
Frequency Control	Synthesized with AFC
Bandwidth	15 kHz
Modulation	FM / FSK
Sensitivity 12 dB S/N	-118 dBm

Installation Options	
Antenna Assembly	Tripod or Fixed Mount
Carrying Case	Pelican Model 1700

System Computer (Optional)	
Processor	Celeron or higher
Operating System	Windows 2000 or higher
Type	Any USB compatible

Figure 3.1 *System parameters of the iMet-3050A*

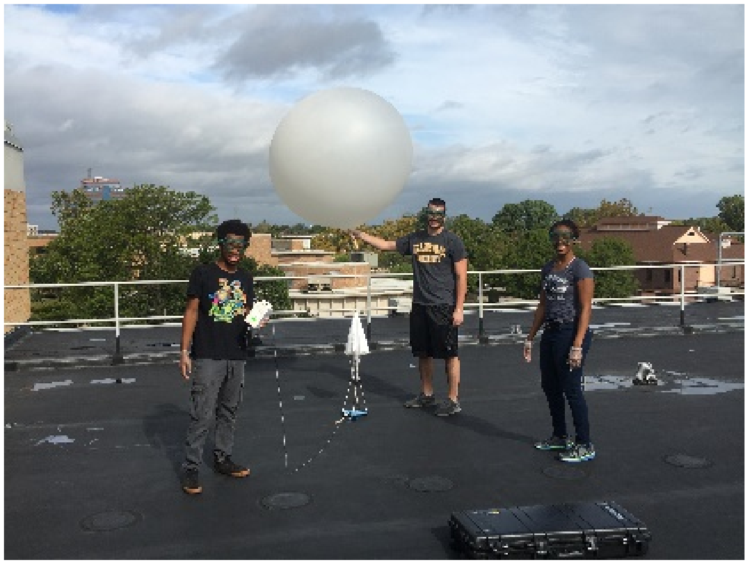

Figure 3.2 *Pictures of a rawinsonde balloon launch done by students on October 9, 2017*

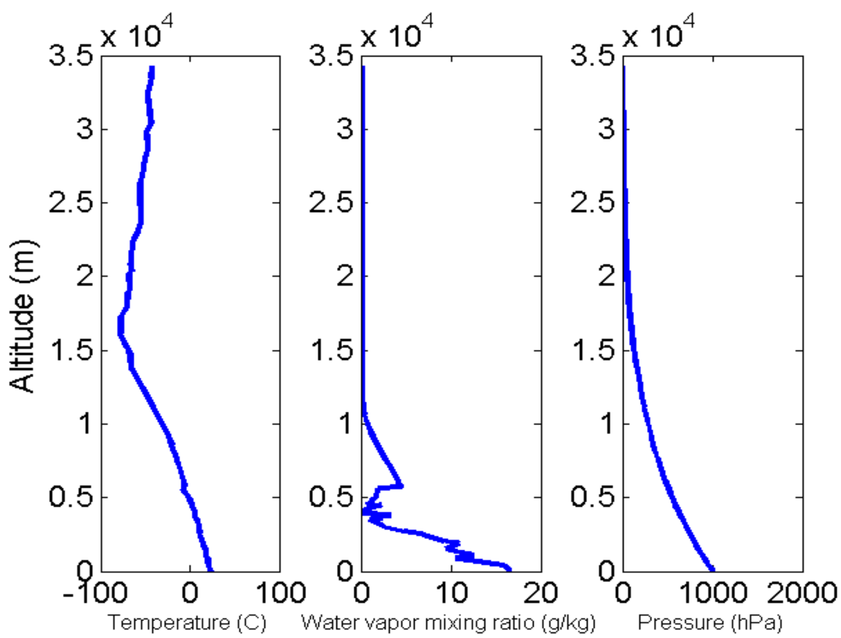

Figure 3.3 *Results obtained from the October 09, 2017 launch.*

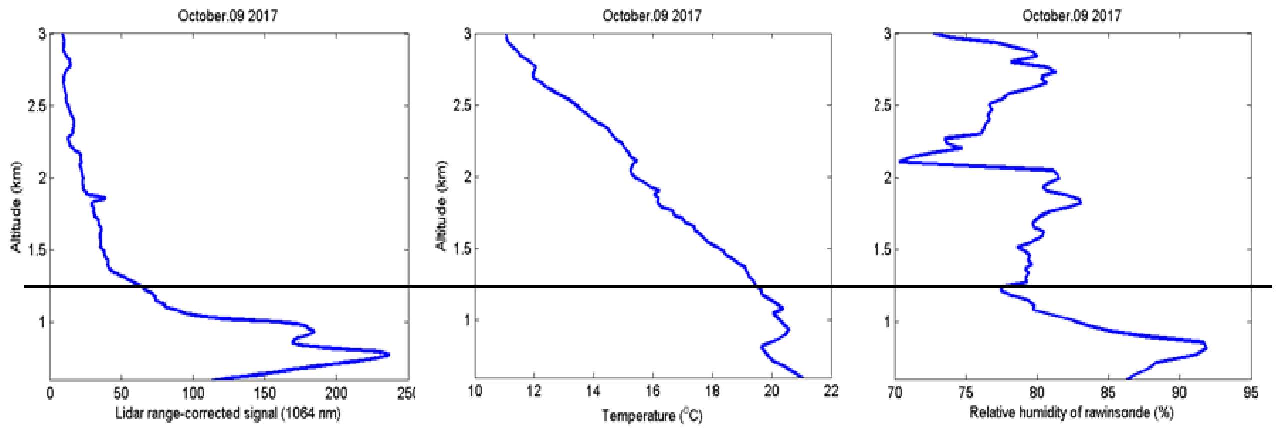

Figure 3.4 *shows planetary boundary layer (PBL) heights retrieved from results of rawinsonde and elastic signal (1064 nm) of HU lidar on October 09, 2017.*

4. <u>The scanning lidar built for studies of water vapor and aerosols in the PBL</u>

We have completed the scanning 14-inch lidar for lower tropospheric research. It has been tested and can provide aerosol and water vapor profiling in the PBL as well as PBL height. Additionally, the lidar has the potential to monitor local regional air quality. A picture of the scanning lidar system is shown in Figure 4.1. Its system parameters are shown on the right of the figure. Two small compact high-frequency lasers emit 16 micro-Joules at 355 nm, and 50 micro-Jules at 1064 nm, at a frequency of 20k kHz. Two-relative-mirrors are placed at the front of laser to align the laser outputs. The atmospheric backscattering is collected by a 14-inch Cassegrain-configured telescope. A Licel data acquisition system is used to digitize the return signal. The Licel system can provide a shared baseline between different signal channels and allow for easier comparison and validation of data taken by the lidar. We have added a Raman water vapor measuring capability to the scanning lidar. The new configuration of the beam-splitting system is shown in Figures 4.2. Figure 4.3 shows 355 nm Range-corrected measurements at an elevation angle of 60^o on July 23 2015. Figure 4.4 shows (a) 386 nm raw N_2 Raman signal (3 minute averaging), (b) 407 nm raw water vapor Raman signal (6 minute averaging) and water vapor mixing ratios at 8:39 EDT on October 12, 2017.

However, this scanning lidar uses manual scanning only and is heavy and cumbersome. The new automatic scanning platform purchased under this BAA funding has been delivered and is being developed. It is shown in Figure 4.5. When it is completed, the new scanning lidar system will automatically scan the atmosphere and obtain 3-D properties of the lower atmosphere.

Laser transmitter: Two Lasers: @355nm 16 μj, 300 mW, Nd:YAG Q-switch, 20khz, pulse width 3ns @1064nm 50μj, 1W, ND:YAG Q-switch, 20khz, pulse width 3 ns
Telescope receiver: Celestron 14 in Schmidt-Cassegrain Catidioptric telescope, Focal length (3910 mm, F/11), Main mirror spherical with the zero power corrector plate holding, Focus is 10-inch from back opening.
Detectors and transient recorder: @1064nm APD @355nm PMT

Figure 4.1 *HU's scanning lidar*

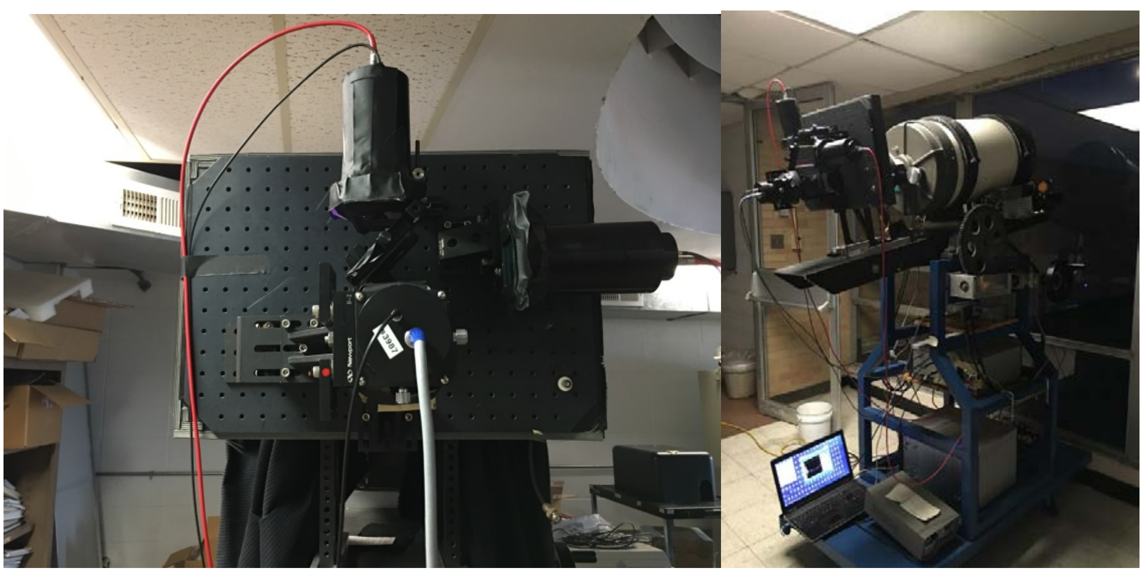

Figure 4.2 *Back and side views showing detector system.*

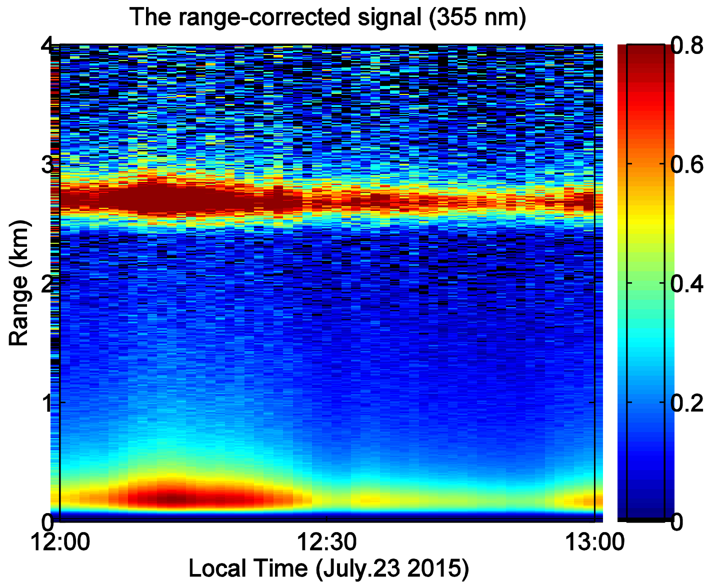

Figure 4.3 *355 nm Range-corrected signal at an elevation angle of 60^o on July 23, 2015.*

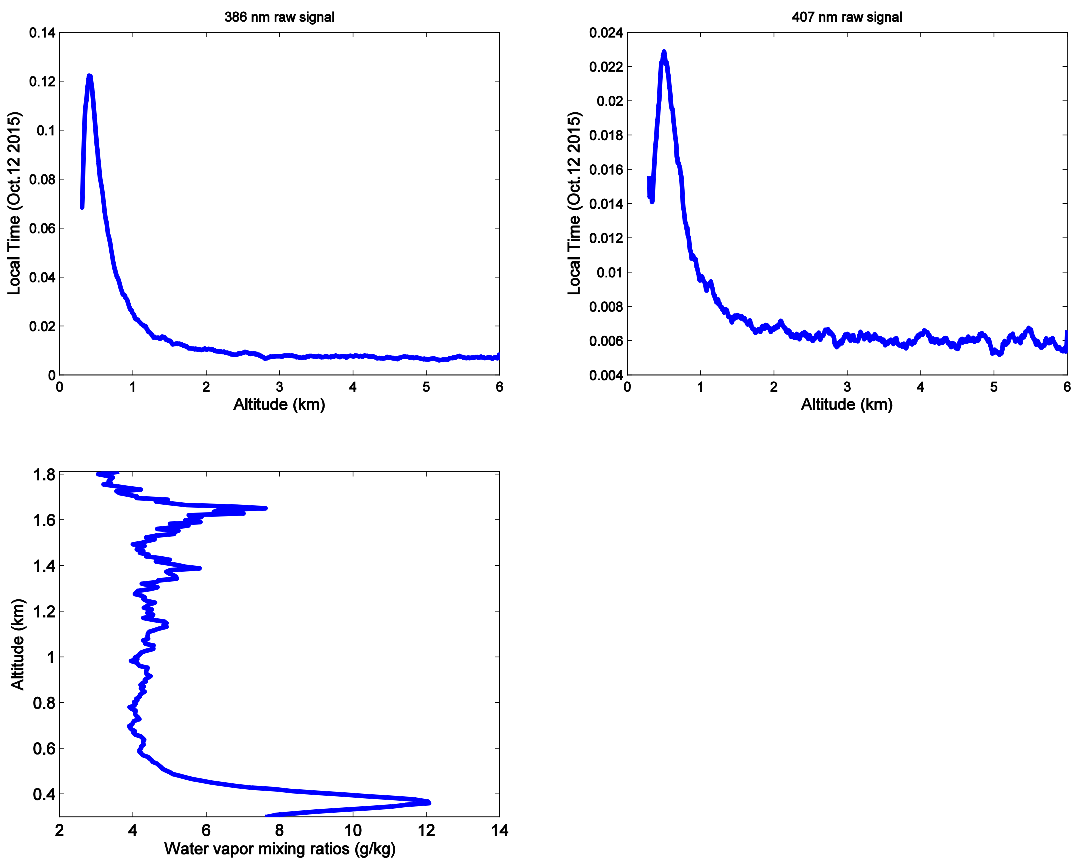

Figure 4.4 *(a) 386 nm raw N_2 Raman signal (average time: 3 minute), (b) 407 nm raw water vapor Raman signal (6 minute averaging) and water vapor mixing ratios at 20:39 on Oct.12 2017.*

Figure 4.5 *New scanning system being developed.*

5. <u>Direct Broadcast Receiving System</u>

HU under non-DoD funding has purchased and installed a Direct Broadcast System (DBS) antenna Receiving and Data Analyses System (See Figures 5.1 and 5.2). This allows us to retrieve real-time data from various satellites automatically when they are within our acquisition of signal capabilities. Presently, we are tracking 11 satellites every day including JPSS-1, Suomi-NPP, Aqua and Terra MODIS, and MetOp A and B. Access to real-time data (such as meteorological, atmospheric constituent, and imagery data) can enhance the effectiveness of our capability to glean information on significant events, especially for upstream events (e.g.: smoke from forest fires, volcanic plumes, dessert dust storms, chemical spills, tornadoes and hurricanes) to measure the necessary parameters and required accuracy needed for decision making, model verification and improvements (e.g., Air Quality models), and validation/calibration studies and campaigns. Figure 5.3 shows an example of a Suomi-NPP Visible Infrared Imaging Radiometer Suite (VIIRS) true-color image taken on October 7, 2016 showing hurricanes Mathew and Nicole.

Figure 5.1 *Installation of the DBS on HU's Harbor Centre Rooftop.*

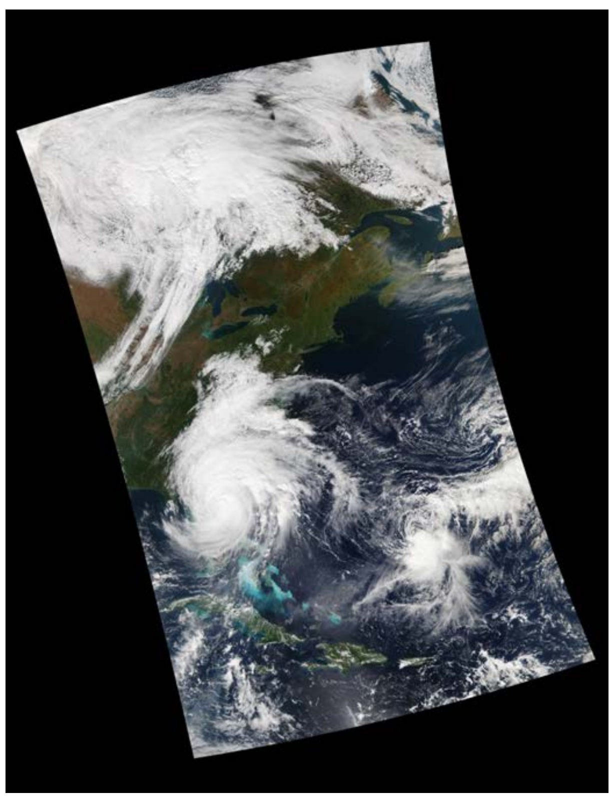

Figure 5.2 *VIIRS satellite imagery on October 16, 2016.*

6. Atmospheric Observation using our Mie-Raman-Differential Absorption (MRDA) lidar and our sun photometer during the August 21, 2017 Solar Eclipse

The local atmospheric measurements were carried out on August 21, 2017, during the 85 % solar eclipse, using a Dial-Mie-Raman Differential Absorption lidar and a sun photometer at Hampton University (HU). The results of aerosol extinction coefficients, planetary boundary layer (PBL) height, water vapor mixing ratios and ozone density before, during and after the solar eclipse were obtained by HU lidar. The multi-wavelength aerosol optical depth (OD), aerosol Angstrom exponents and fine and coarse aerosol ODs are measured by our sun photometer during the same time period. The data of the two types of measurements demonstrate atmospheric dynamic variation with certainty that the solar eclipse affects the meteorological parameters of the atmosphere near the ground, the ozone concentration near the ground, and the height of the mixing layer. It was found that a certain time delay exists for the solar eclipse impact on the meteorological parameters, the ozone concentration and the mixing layer height. Students participated in this event and gained a new understanding of the atmospheric effects of solar heating and the resulting lower atmospheric mixing.

Solar Eclipse information:

Hampton, Virginia, USA

Partial solar eclipse visible (85.60% coverage of Sun)

Magnitude: 0.8804

Duration: 3 hours, 45 minutes, 18 seconds

Partial begins: Aug 21, 2017 at 12:20:52 pm

Maximum: Aug 21, 2017 at 2:46:53 pm

Partial ends: Aug 21, 2017 at 4:06:10 pm

Times shown in local time (EDT)

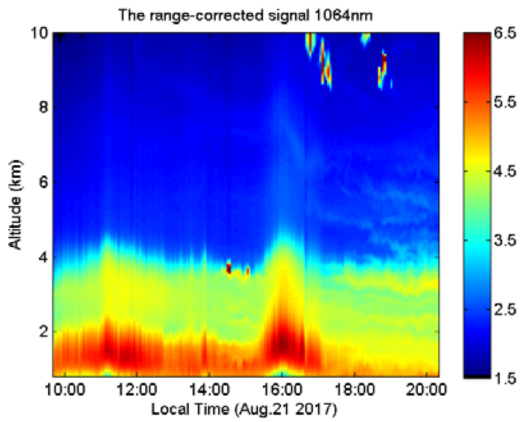

__Fig. 6.1__ Lidar RCS at 1064 nm

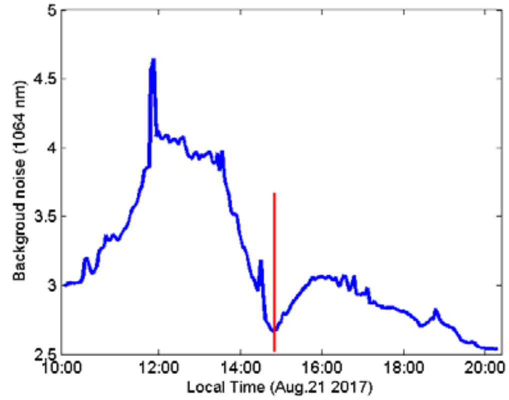

__Fig.6.2__ Lidar Background noise (sunlight energy)

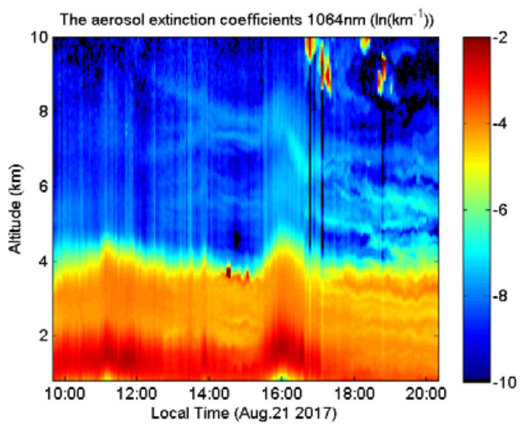

__Fig.6.3__ Aerosol extinction at 1064 nm

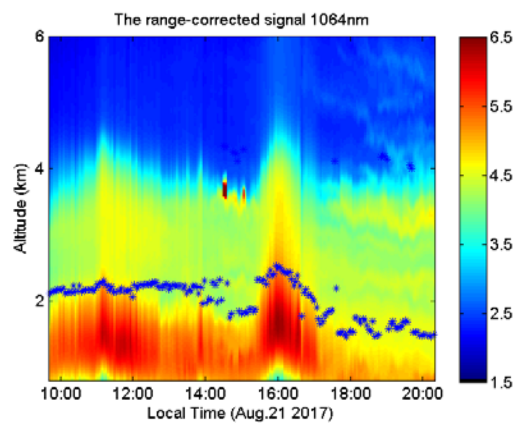

__Fig. 6.4__ PBL mixing and height (dots)

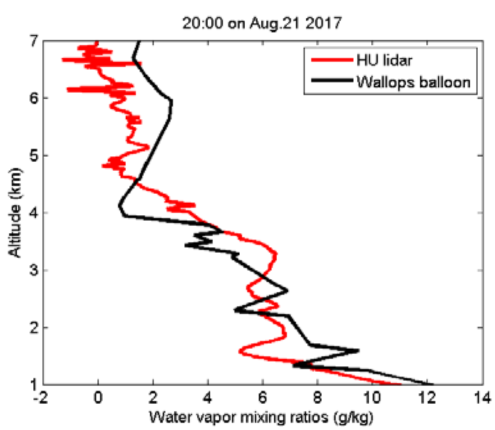

__Fig.6.5__ Water vapor mixing ratio from Raman lidar compared with a rawinsonde profile.

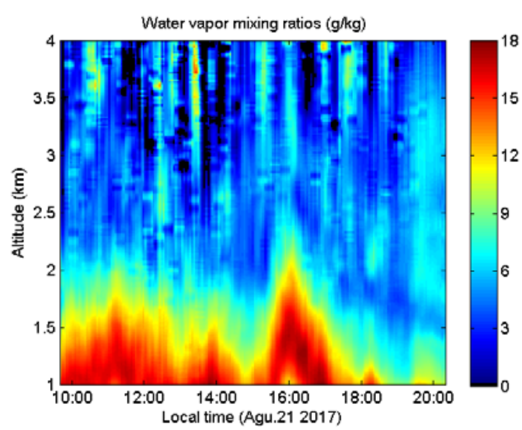

__Fig.6.6__ Water vapor variation from 10:00 am to 8:00 pm EDT using Raman lidar.

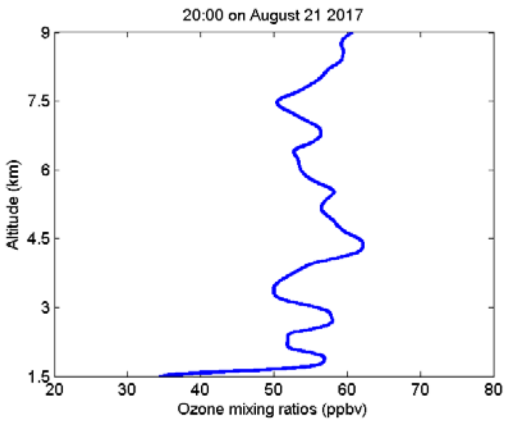

Fig.6.7 *OPO-derived Ozone profile*

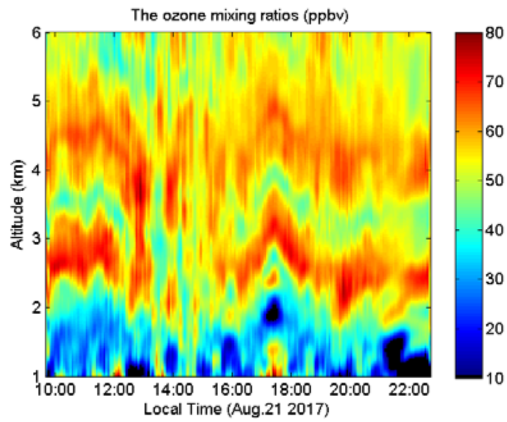

Fig.6.8 *Ozone variations from 10:00 am to 10:00 pm EDT.*

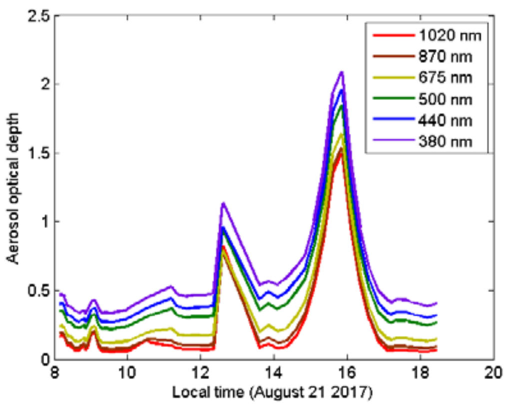

Fig.6.9 *shows multi-wavelength aerosol OD.*

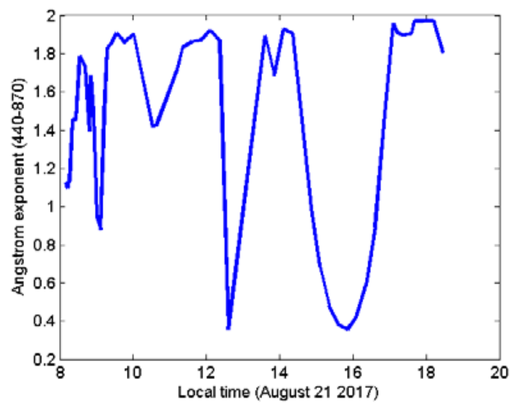

Fig. 6.10 *Angstrom exponents (440 nm-870 nm).*

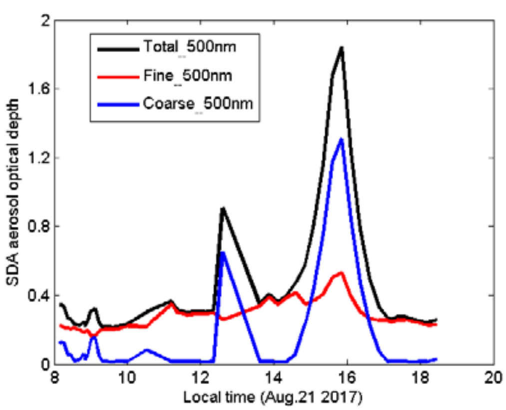

Fig. 6.11 *Coarse and fine aerosol OD.*

Eclipse measurement results were obtained using the new Mie-Raman-Differential Absorption tunable Lidar. Fig. 6.1 shows lidar range-corrected signal at 1064 nm. Fig.6.2 shows lidar background noise and its positive relationship with sunlight heating. The red line in Fig.6.2 indicates the time of maximum solar eclipse. Fig.6.3 shows the PBL height using the wavelet method. Fig.6.4 shows aerosol extinction variation at 1064 nm. Fig.6.5 shows water vapor mixing ratio retrieved using lidar compared with results from a rawinsonde. Fig.6 shows water vapor variation from 10:00 to 20:00 EDT. Fig.6.7 shows an ozone profile retrieved using lidar. Fig.6.8 shows ozone variation from 10:00 to 22:00 EDT. From the aerosol and water vapor results, we can deduce that were they both affected by sunlight heating. Fig.6.9, 6.10 and 6.11 show multi-wavelength aerosol optical depth (OD), Angstrom exponents (440 nm-870 nm), and coarse and fine aerosol OD, respectfully for August 21 2017 solar eclipse event.

7. Student Education and Training

We are developing creative students in the area of atmospheric science and remote sensing. Two of our recent graduates are now working at the NASA Langley Research Center, and one at the NASA Goddard Space Flight Center. One student has taken all of her coursework including her Ph.D. qualifying exams. One Ph.D. student is studying pattern recognition and routinely using our lidar data for monitoring and profiling the structure of atmospheric temperature, water vapor, aerosols, clouds and the PBL. The BAA project is providing a strong program to conduct this basic atmospheric research and producing a pool of skilled graduates in this field. Raman and wind lidars provide excellent multi-discipline training in optics, lasers, detectors, electronics, computer programming, algorithm development, analysis techniques and atmospheric science. Studies include visibility and air quality, aerosol and cloud science, atmospheric scattering theory, atmospheric spectroscopy, statistical treatments in data analyses, atmospheric transport, instrumentation developments and applications, and participation in studies using lidar networking.

8. Research Assistant Professors, and Post-Doctoral and Visiting Scientists

Dr. Jia Su (Atmospheric and Planetary Sciences Department, Research Assistant Professor Hampton University, [HU]) Contributions to BAA:

Dr. Su is in charge of the instrument development and operations of the HU 48-inch lidar facility. He also leads all of the routine data analysis for the lidar data and has increased the lidar capabilities to make temperature profile measurements using anti-Stokes lines in the near UV, as well as general improvements to retrieval algorithms. Dr. Su is also assisting graduate students regarding these developments.

Dr. Michael T. Hill (Atmospheric and Planetary Sciences Department, Research Assistant Professor, Hampton University [HU]) Contributions to BAA:

Dr. Hill has been researching the characterization of Polar Stratospheric Clouds (PSCs) using primarily CALIPSO data, which occur in both polar regions during local winter. These clouds are exceedingly important and necessary for the development of the annual ozone hole over the poles and, therefore, to global ozone depletion studies and for understanding polar region attenuation in the stratosphere. Dr. Hill is also studying the global and seasonal distribution of cirrus clouds using measurements made by CALIPSO, routinely analyzing the time series of the cirrus cloud frequency, optical depth, geometric thickness and the distribution of sub-visual and thin cirrus clouds. That data is compared to our local long term cirrus data taken with the 48-inch lidar. He is also working with students on analyses and computer skills.

Ph.D. Students:

Liqiao Lei (Atmospheric and Planetary Sciences Department)

Ms. Lei has developed a new method to retrieve the planetary boundary layer height using our 48-inch lidar data. She is researching aerosol pattern recognition techniques with lidar and other data in order to determine the particle size and the fractal dimensions of aerosols and clouds, has passed her qualifying exams, and is now a full-time graduate student working on her Ph.D.

Steven Buckner (Atmospheric and Planetary Sciences Department)

Mr. Buckner completed his BS degree in Physics at UMBC, and matriculated to our Ph.D. program during the summer of 2014. Steven is working on the HU scanning lidar and with routine lidar data collection.

9. Journal Publications and Conference Presentations

9.1 Peer review Journal Articles:

1. Jia Su, M. Felton, L. Lei, M. P. McCormick, R. Delgado, and A. St. Pé (2016), Lidar remote sensing of cloud formation caused by low-level jets, J. Geophys. Res. Atmos., 121, doi:10.1002/2015JD02459.

9.2 Conference presentations / invited talks

1. Liqiao Lei, M. P. McCormick, John Anderson, "The Effect of Cirrus Clouds on Water Vapor Transport in the Upper Troposphere and Lower Stratosphere", 2017 AGU Meeting in New Orleans.

2. M. P. McCormick and J.M. Zawodny, Invited paper, "An Advanced SAGE III Instrument on the International Space Station", 2016 AGU Meeting in San Francisco.

3. Jia Su, M.P. McCormick, Liqiao Lei, Invited presentation title "Research on properties of low cloud using multi-wavelength Mie-Raman Lidar" was presented at Fifth International Symposium on Atmospheric Light scattering and Remote Sensing (ISALSaRS17).

4. Sean Leavor and M.P. McCormick, Poster, "Tracking Volcanic Aerosols Using CALIPSO Data and HYSPLIT Trajectory Analysis", 28th ILRC in Romania

<u>9.3 Papers in Preparation to be Submitted:</u>

1. Liqiao Lei, M. Patrick McCormick, Jia Su and Robert B. Lee III, "Fractal analysis of multi-wavelength elastic lidar data for planetary boundary layer height determination", Journal of Atmospheric and Oceanic Technology (in review)

2. Jia Su, M. Patrick McCormick, "Research on properties of low cloud using multi-wavelength Mie-Raman Lidar", Atmospheric Environment (in review)