Scope of Work For

Project 14-006
Characterization of Boundary-Layer Meteorology During DISCOVER-AQ Using Radar Wind Profiler and Balloon Sounding Measurements

Prepared for

Air Quality Research Program (AQRP)
The University of Texas at Austin

by

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1. Abstract

Boundary-layer meteorological processes have a strong impact on the spatial and temporal characteristics of air quality in and around the greater Houston area. To provide data to help characterize these processes during the DISCOVER-AQ project, radar wind profilers (RWPs) were operated at seven sites. The radar wind profilers provided hourly vertical profiles of winds and reflectivity data that can be used to identify mixing heights. In addition, daily meteorological and ozone soundings were taken at several sites on most days during the study.

The primary goal of this proposed project is to use the above measurements to characterize the atmospheric boundary layer (ABL) processes that were occurring during DISCOVER-AQ. The study will focus on vertical and spatial structure of aloft winds, transport patterns, the diurnal and spatial characteristics of daytime mixing heights, how the large-scale meteorological conditions influenced these characteristics, and how the ABL meteorology influenced the general air quality in the greater Houston area. A secondary goal is to provide context to the DISCOVER-AQ boundary layer characteristics by comparing them to characteristics (1) observed on days of high ozone concentrations during the Texas Air Quality Study II (TexAQS-II) and (2) observed over the past 10 years (specifically in regard to the vertical ozone structure and general meteorological conditions). A third goal is to provide a data set of ABL measurement results for use by other researchers.

This project will provide (1) a basis for understanding key meteorological processes, which stand alone but can also assist other researchers with the interpretation of other measurements collected during DISCOVER-AQ; (2) a data set of daytime mixing heights that will be very helpful for the interpretation of aircraft- and satellite-based measurements of air quality; (3) context for the results derived from data collected during DISCOVER-AQ; and (4) information and a data set to support verification and evaluation of meteorological models used in the photochemical grid modeling.

2. Technical Work Plan

Sonoma Technology, Inc. (STI) and our collaborator Gary Morris from Valparaiso University will characterize the atmospheric boundary layer meteorological processes during DISCOVER-AQ and supply resulting data products to support other DISCOVER-AQ research.

As part of the DISCOVER-AQ project, STI and the National Oceanic and Atmospheric Administration (NOAA), with support from the University of Texas at Austin, operated RWPs at four sites in the greater Houston area to collect boundary layer wind data. In addition, a permanent network of three RWPs also provided data during this study. Pennsylvania State University and the Valparaiso University/University of Houston team conducted daily meteorological and ozone soundings on most days during DISCOVER-AQ. The combination of these data provides a rich source of information characterizing the boundary layer meteorology; this information can be used to provide insight into the processes that influence the air quality in Houston, and also can be used to support other analyses for DISCOVER-AQ.

This project has three main elements: (1) characterize the ABL processes on all flight days and high ozone days during the DISCOVER-AQ study period; (2) evaluate the representativeness of the boundary-layer conditions during DISCOVER-AQ relative to TexAQS-II and over the past 10 years for the month of September; and (3) provide continuous daytime boundary layer height data at the seven RWP sites for the entire study period. (Note that the RWP boundary layer winds for four sites are being delivered by STI under a separate contract.)

The remainder of this work plan provides a brief overview of the RWP and balloon sounding measurements (Section 2.1); a statement of work to meet the project goals (Section 2.2); a summary of STI's qualifications, and past project examples (Section 2.3), résumés for the Principal Investigator (PI) and Co-PI (Section 3); prior support from AQRP (Section 4); and references (Section 5).

2.1 Background on the Boundary Layer Measurements to Be Used in This Project

The 915 MHz RWPs collected continuous (hourly) vertical profiles of boundary layer winds from about 100 m to about 3,500 m agl. The RWP backscatter data can be used to estimate continuous (hourly or sub-hourly) daytime boundary layer heights up to 3,500 m agl. The balloon soundings provide a snapshot of vertical profile of winds, temperature, relative humidity, and ozone from the surface to above 15,000 m agl. **Figure 1** shows the locations of RWPs and the sounding launches during DISCOVER-AQ that will provide the data to be used in this proposed project.

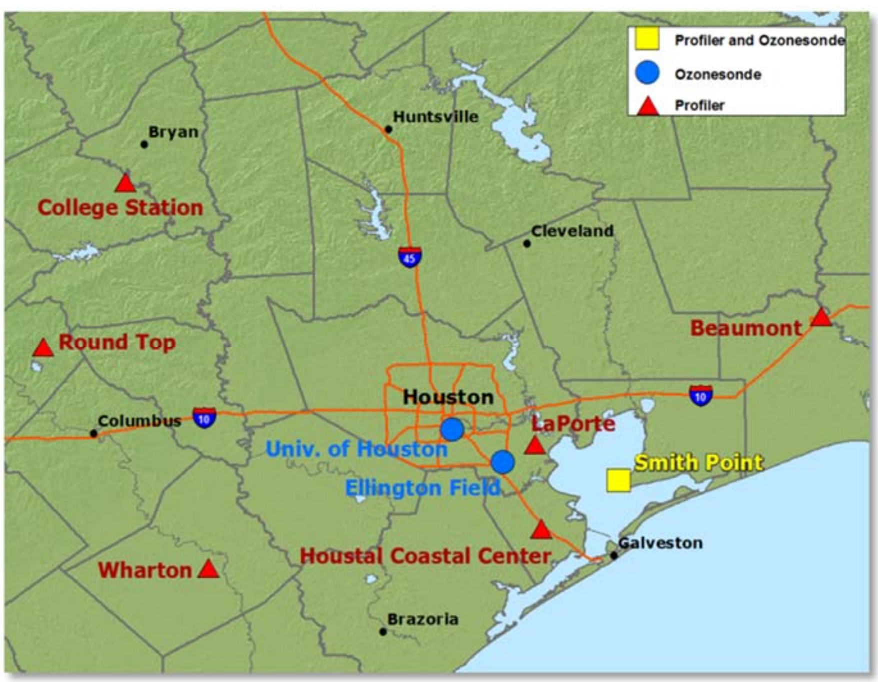

Figure 1. Locations of upper-air sites that we will use to characterize ABL processes.

Data are available from all seven radar wind profilers from August 22, 2013, through October 22, 2013. Balloon sounding data are available for almost all days during DISCOVER-AQ at one or more of the sites. An example of the RWP wind data collected at Smith Point is shown in **Figure 2**, showing complex flows within the ABL.

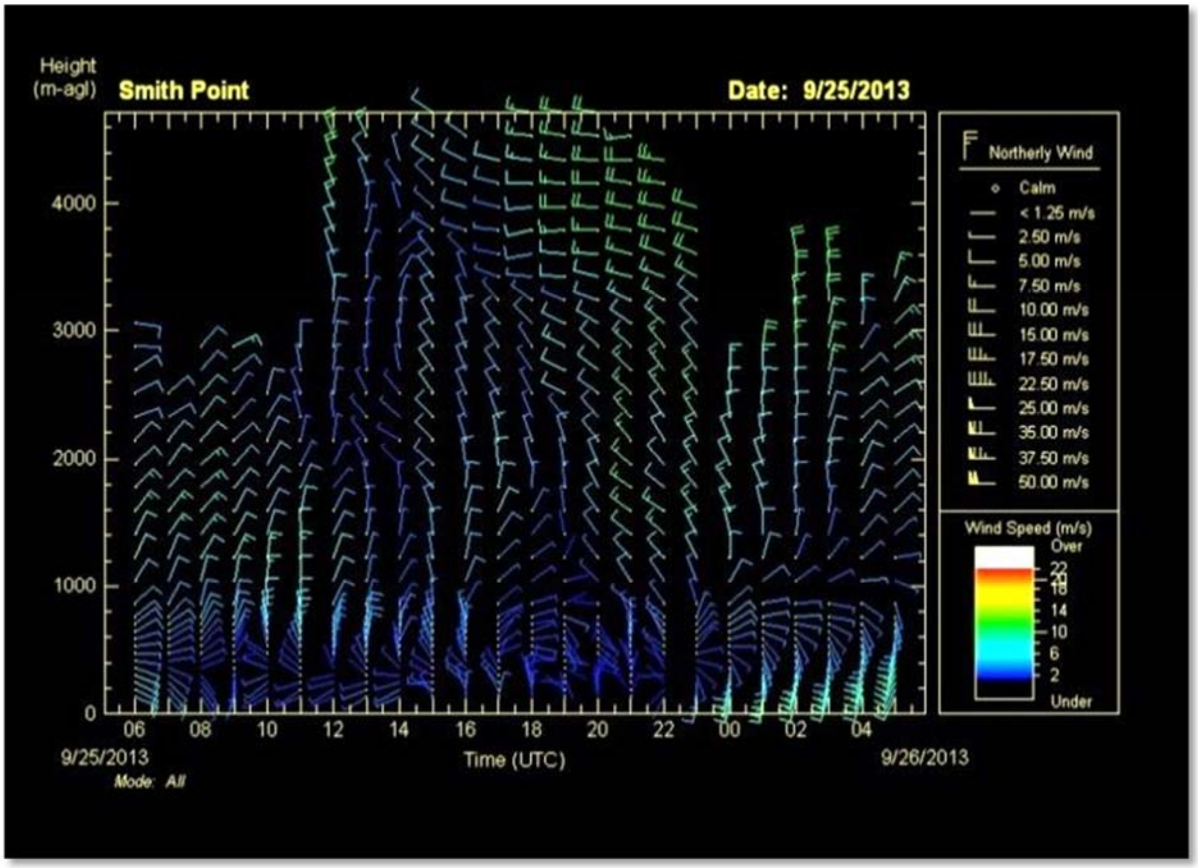

Figure 2. Example of RWP wind data collected at Smith Point showing complex flows within the ABL.

The RWPs used in this study consisted of a single phased-array antenna. The radar beam is electronically pulsed vertically, 23° from the vertical, in any of four orthogonal directions. The RWP transmits an electromagnetic pulse along each of the beam directions, one at a time. These signals are then scattered by small-scale turbulent fluctuations in the atmosphere. A receiver measures the fraction of the transmitted energy that is scattered back toward the RWP (referred to as “backscattering”). These backscattered signals are received at a slightly different frequency than the transmitted signal. This difference is called the Doppler frequency shift and is directly related to the velocity of the air moving toward or away from the RWP along the direction the beam is pointing (radial velocity). Using appropriate trigonometry, the three-dimensional meteorological velocity components (u, v, w) and wind speed and wind direction are calculated from the radial velocities. For each hourly average, a minimum of 60%

of the data collected during the hour must fall within a 3.0 m/s consensus window to be included in the hourly average. Consensus windows are determined for each velocity component.

The mixing height is defined as the vertical extent to which pollutants, emitted at the surface, mix. For this study, mixing heights will be estimated by using RWP backscatter data. Backscatter is strongly influenced by the refractive index of the atmosphere. Turbulence produces variations in atmospheric temperature, humidity, and pressure, which in turn cause variations in the radar refractive index. In the planetary boundary layer (PBL), humidity fluctuations contribute most to the variations in the radar refractive index. The greatest humidity variations tend to occur at the top of the convective or marine boundary layers. For example, Wyngaard and LeMone (1980) showed that the radar refractive index peaked at the inversion at the top of the convective boundary layer (CBL) because of the entrainment of warm, dry, aloft air into cooler, moister air below the inversion.

A RWP, like all radar, is sensitive to reflections from other targets and to electromagnetic radiation from sources other than the atmosphere. For instance, aircraft, birds, or insects may generate spurious radar echoes that can be mistaken for an atmospheric return. Migrating birds are a well-documented source of wind measurement errors, especially in Texas. For DISCOVER-AQ, the RWPs produced data with good height and time coverage (Knoderer and MacDonald, 2013); thus, those data will be very useful for characterizing wind patterns within the ABL. During data quality control performed under a separate contract, STI staff removed spurious data values due to bird interference, which primarily occurred at night. At the Wharton Airport RWP site, a nearby rotating radar caused interference of the RWP at night; under these circumstances, these data values were removed from the data set.

The balloon sounding system consisted of the ECC type En-Sci 2Z ozonesonde instruments (Komhyr, 1969) with 0.5% buffered KI cathode solutions (solutions prepared by B. Johnson, NOAA Climate Monitoring and Diagnostics Laboratory), as recommended by the Jülich Ozone Sonde Intercomparison Experiment (JOSIE) (Smit et al., 2007). Meteorological measurements are provided by the InterMet system. On-board global positioning systems (GPS) provided latitude, longitude, altitude, wind speed, and wind direction data. The effective vertical resolution of the ozone profile data is about 125 m. All data were processed with Holger Voemel's STRATO software or NOAA's SkySonde software, and data for all nominal flights were posted to the project website
(physics.valpo.edu/ozone).

The Tropospheric Ozone Pollution Project began in Houston in July 2004. To date, the database includes about 500 ozone profiles for areas in southeast Texas, mostly from the Rice University or University of Houston campuses. The project has been continuously funded since its inception, with funding from the Shell Center for Sustainability at Rice University, the Texas Commission on Environmental Quality, the AQRP administered by the University of Texas, and NASA's Division of Earth Science. Additional support has been provided by Valparaiso University. An example of a balloon sounding that will be used in this project is shown in **Figure 3**. The mixed layer depths can be identified in the sounding data at the locations of sharp vertical gradients in temperature, relative humidity, ozone, and potential temperature. A software analysis provides the initial estimate, which is confirmed by visual inspection of each profile. Both estimates are provided in our deliverable product. When the two disagree, we recommend using the visual inspection value.

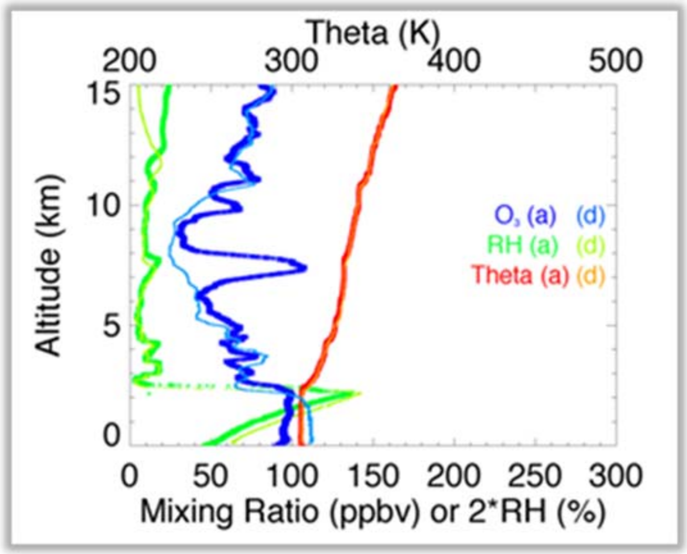

Figure 3. Example of a balloon sounding taken during DISCOVER-AQ.

2.2 Technical Approach

2.2.1 Task 1: Characterize the Atmospheric Boundary Layer

For this task, STI and Valparaiso University will characterize the meteorological processes on all NASA aircraft flight days and on days when 8-hour ozone exceeded 75 ppb in Houston during the DISCOVER-AQ study period. The dates of these flights and days of high ozone concentrations are shown in **Table 1**.

Table 1. Days for which we will characterize ABL processes and the associated Metropolitan Houston maximum 8-hour ozone concentrations and NASA DISCOVER-AQ flight days.

Date	Metro-Houston Maximum 8-hr Ozone (ppb)	DISCOVER-AQ Flight Day
8/28/2013	**83**	
8/29/2013	**78**	
8/30/2013	**78**	
8/31/2013	**84**	
9/4/2013	62	✓
9/6/2013	45	✓
9/11/2013	51	✓
9/12/2013	66	✓
9/13/2013	66	✓
9/14/2013	64	✓
9/24/2013	51	✓
9/25/2013	**124**	✓
9/26/2013	**89**	✓
9/27/2013	**76**	
10/8/2013	**85**	
10/9/2013	**99**	

The end product will be a description of the meteorological characteristics for each day, as well as a discussion of the interrelation among the meteorological phenomena and the general air quality conditions. Again, for this task, we will focus on the vertical and spatial structure of aloft winds, transport within the ABL, the diurnal and spatial characteristics of daytime mixing heights, how the large-scale meteorological patterns influence these processes/characteristics, and general relationships between the above and surface air quality. In particular, we will describe and display the following for each day:

- **Boundary Layer Winds:** We will characterize the diurnal and spatial changes in the boundary layer wind patterns by reviewing hourly radar profiler wind collected at all seven RWP sites and from the balloon soundings from the three sites. The existence, timing, and strength of synoptic winds, the land breeze, the Bay breeze, and the Gulf breeze will be noted, along with their relationship to the vertical mixing and the large-scale weather pattern.
- **Boundary Layer Transport:** For selected receptors, we will run 24-hour back-trajectories for several altitudes within the ABL, starting near the time of peak ozone concentrations. We will use NOAA's trajectory tool (esrl.noaa.gov/psd/programs/2013/texaqs/traj/) to run the trajectories using the RWP wind data.

- **Vertical Mixing:** In Task 3, we will estimate the hourly height of the daytime surface-based mixed layer from the RWP reflectivity data at all seven sites and from the balloon sounding data. We will use the mixing height data to determine the characteristics of the daytime mixing layer, including the period of CBL growth, the maximum height of the CBL, the time of maximum height of the CBL, and any undercutting of the CBL by the Bay and/or Gulf boundary layers.
- **Vertical ozone structure:** To characterize the vertical distribution of ozone, we will examine plots of the vertical ozone profiles from the three sites. We will determine the relationship between the boundary-layer winds and transport patterns (via the RWP trajectories), mixing heights, and vertical ozone structure.
- **Large-Scale Aloft Weather:** We will use the height of the 500-mb constant-pressure level and winds at 500 mb as depicted on the National Weather Service (NWS) Daily Weather Maps to characterize the aloft large-scale weather patterns that existed at 0600 CST on each day. Locations and strengths of ridges, troughs, and circulation patterns will be noted, along with their probable influence on mixing and cloud cover in the Houston area.
- **Large-Scale Surface Weather:** We will use the large-scale surface pressure pattern and regional winds as depicted on the NWS Daily Weather Maps to characterize the large-scale surface flows that existed at 0600 CST on each day. General locations of surface highs and lows will be noted, along with their probable influence on ABL winds in the Houston area.
- **General Ozone Patterns:** We will analyze spatial and temporal ozone patterns by reviewing hourly spatial plots of ozone data collected at routine monitoring sites in the Houston and Galveston Bay area and the ozonesondes. In conjunction with the meteorological data discussed above, we will review the ozone data.

The work on this task will be shared by STI and Valparaiso University. We will summarize the results from the above analyses in the final report.

2.2.2 Task 2: Determine Representativeness of Meteorological Conditions

The goal of Task 2 is to provide context to the DISCOVER-AQ boundary layer characteristics by comparing them to characteristics (1) observed on days of high ozone concentrations during TexAQS-II, and (2) observed over the past 10 years (specifically in regards to the vertical ozone structure and general meteorological conditions). The dates of comparison from TexAQS-II will include June 22 to 25, 2005; July 31 to August 2, 2005; and August 31 to September 2, 2006. These dates have been selected because a detailed analysis of boundary conditions has already been performed for these dates, and high ozone concentrations were reported on these dates (MacDonald and Knoderer, 2008). We can compare data from other TexAQS-II days as requested and mutually agreed.

For the TexAQS-II comparison subtask, we will

- Analyze the diurnal and spatial characteristics of the boundary layer winds and mixing heights. We will note similarities and differences between the selected TexAQS II days and the selected DISCOVER-AQ days (see Table 1).
- Analyze general transport patterns and note similarities and differences between TexAQS II days and the selected DISCOVER-AQ days.
- Analyze aloft ozone patterns using the sounding data and note similarities and differences between TexAQS II days and the selected DISCOVER-AQ days.
- Identify any days that have very similar meteorological patterns; then, for these days determine how the boundary layer meteorological conditions explain differences in observed ozone concentrations.

For the 10-year data comparison subtask, we will put the DISCOVER-AQ ozone profiles and general meteorological conditions in context by

- Comparing profiles during DISCOVER-AQ to the September average profiles for each of the last ten years and to selected profiles on days of high ozone concentrations during those 10 years.
- Examining the meteorological variability over that 10-year period to understand the context for the meteorological conditions observed during DISCOVER-AQ.

The work on this task will be shared by STI and Valparaiso University. We will provide a narrative and supporting figures summarizing the findings in the final report.

2.2.3 Task 3: Derive and Deliver Continuous Mixing Heights

For this task, we will produce hourly daytime mixing heights for all seven RWP sites and non-continuous mixing heights using the balloon sounding data from three sites for the entire DISCOVER-AQ period. The resulting data will be made available to other researchers. To determine mixing heights from the RWP data, we will analyze time-height cross-sectional plots of the RWP signal-to-noise ratio (SNR), vertical velocity, spectral width data, and wind data. At times, the peak SNR may not always define the surface-based mixed layer and may depict some other aloft layer, such as a subsidence inversion or a cloud layer; the vertical velocity, spectral width, and RWP winds will help determine the surface-based mixing height. STI will perform the work on this task, and the findings will be provided in an Excel file. Data files pertaining to this task and the other tasks outlined in this work plan will be delivered to the University of Texas for storage at the Texas Advanced Computing Center (TACC).

2.2.4 Task 4: Reporting

The project team will produce and deliver an executive summary at the beginning of the project, monthly technical and financial reports, quarterly reports, a draft final report, a final report, and a final presentation. The parties responsible for these deliverables and the schedule of deliverables are shown in **Table 2**. Please note that we would like to perform this work in a short time frame so that the data can quickly be provided to other researchers to support their analyses. The Technical, Draft Final, and Final Reports will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources.

Table 2. Deliverables and work schedule, assuming a start date of May 1, 2014.

Deliverables	Party Responsible	Completion Date
Monthly technical reports	STI	8th day of each month
Monthly financial reports	STI	12th day of each month
Quarterly reports; summary of project status	STI	Last day of each quarter
Draft final report	STI and Valparaiso University	July 31, 2014
Mixing heights spreadsheet	STI	July 31, 2014
Final report	STI and Valparaiso University	August 31, 2014
End of project presentation	STI and Valparaiso University	June 2015

2.3 Research Experience

STI was founded in 1982 to provide air quality and meteorological research, services, and specialty products for government and industry. Clinton MacDonald, the proposed PI, and other supporting staff assigned to this project have extensive experience with characterizing boundary layer meteorological processes that influence air quality using RWP and other meteorological observations including for the greater Houston area and Texas. Gary Morris, from Valparaiso University and the Co-PI, has extensive experience in analyzing ozone profiles and associated meteorological data to help understand boundary layer ozone characteristics and processes. He has performed extensive measurements and analysis for Texas. Full résumés that provide more details on the PI and Co-PI's experience are provided in Section 3. Three examples of projects performed by the PI are provided below. Additional project examples can be provided upon request.

2.3.1 Project Name and Contract Date: Texas Radar Wind Profiler Deployment, 6/25/2013–ongoing

Client: The University of Texas at Austin and the Texas Commission on Environmental Quality (TCEQ); Vince Torres, (512) 471-5803.

Description: STI and NOAA deployed four RWPs in and around the greater Houston area from about August 22 until October 20, 2013, to support NASA's DISCOVER-AQ project. A key goal of DISCOVER-AQ is to improve our ability to use satellite data to diagnose the spatial distribution of air pollution in the atmospheric boundary layer. Improved observations from space could help improve air quality forecasts and our understanding of pollutant transport; using those observations, we can better assess the spatial variability of emissions. Better use of satellite data to measure and characterize the processes that influence air pollution requires measurements of boundary layer winds and mixing heights that are provided by RWPs.

2.3.2 Project Name and Contract Date: Cleveland Multiple Air Pollutant Study, 6/29/2009–2/28/2010

Client: Environmental Protection Agency, Office of Research and Development, via Alion Science and Technology; Keith Kronmiller, (919) 541-3566.

Description: STI provided meteorological data to support data analysis and modeling to investigate sources of air pollution in the Cleveland metropolitan area, and to determine how these sources vary across Cleveland and the surrounding areas. STI operated a radar wind profiler, minisodar, and surface meteorological instruments from July 24, 2009, through February 28, 2010. To identify meteorological phenomena important to the transport and dispersion of air quality, STI quality-controlled and analyzed mixing height and hourly wind and temperature data.

2.3.3 Project Name and Date: Radar Wind Profiler Data Quality Control and Mixing Height Detection for TexAQS-II, 5/1/2007–8/31/2007

Client: Texas A and M and Texas Commission on Environmental Quality; Dr. John Nielsen-Gammon.

Description: The TexAQS-II was designed to provide support for state implementation plan (SIP) revisions. As part of the TexAQS-II study, various organizations made upper-air meteorological measurements using twelve 915 MHz RWPs, three 404 MHz RWPs, nine Radio Acoustic Sounding Systems (RASS), two sodars, and one lidar. STI provided TCEQ and other scientists with data that could be immediately used in analysis and modeling without the need for judgment regarding data quality. STI derived mixing heights from the RWP reflectivity data, then performed quality control of the wind, temperature, and mixing height data collected for the 15 sites during the 18-month field study.

3. Curriculum Vitae

Mr. Clinton P. MacDonald

Dr. Gary A. Morris

Clinton P. MacDonald

Group Manager, Meteorological and Air Quality Measurements

Mr. MacDonald joined STI in 1996. His areas of expertise include meteorological and air quality analysis; air quality forecasting; boundary-layer meteorological measurements using radar wind profilers (RWPs), sodars, and microwave radiometers; and managing complex field studies using highly sophisticated instrumentation in challenging environments to characterize and understand meteorological and chemical characteristics and processes and to provide data to support meteorological modeling and forecasting. He has extensive experience in, and in-depth knowledge of, instrumentation, data validation, data analysis, and modeling.

Mr. MacDonald is leading the deployment of four RWPs in Texas in support of NASA's DISCOVER-AQ project. He was Project Manager for the 2010 to 2012 Air-Sea Interaction Study (which included operating and delivering data from a minisodar and a microwave radiometer) and the 2005 to 2006 TexAQS-II offshore RWP measurement project, which included one RWP and one minisodar. In 2012, he led the deployment of a sodar to support the development of new wind energy technology. In addition, he led the design, implementation, and operation of a meteorological monitoring site at Oceano Dunes, California (2010), and is the Principal Investigator/Project Manager for the operation and maintenance of five upper-air meteorological sites (four RWPs, four minisodars, and a microwave radiometer) for the South Coast Air Quality Management District (SCAQMD, 2006 to 2013). He is also the Project Manager for the calibration and audits of the State of California's near-road meteorological monitors (2009 to 2013). As part of STI's participation in a Cooperative Research and Development Agreement (CRADA, ongoing since 1991), he serves on the Application Advisory Group for commercializing the National Oceanic and Atmospheric Administration's (NOAA) boundary-layer RWP technology, including the LAP-3000 RWP. His role in the CRADA is to identify new applications for RWP products and to design and oversee the creation of RWP application software.

Education

- MS, Atmospheric Science, University of California at Davis
- BS, Atmospheric Science, University of California at Davis

For a complete list of publications, see sonomatech.com/ResPub/CPMpub.pdf.

Mr. MacDonald has published several journal articles on meteorological and air quality processes, coauthored the U.S. Environmental Protection Agency's (EPA) guidance document on developing an air quality forecasting program, and authored many formal reports on air quality transport and dispersion. He developed and taught numerous courses, including (1) EPA's 2002, 2003, and 2004 National Air Quality Forecasting Conference courses on air quality forecasting; (2) EPA-sponsored 2003 Regional PM Air Quality Forecasting workshops; and (3) the 2003 American Meteorological Society course titled "RWP Observations, Applications, and Analysis." In addition, Mr. MacDonald held the position of Adjunct Professor of Meteorology at Santa Rosa Junior College.

Mr. MacDonald has led and participated in many data analysis projects to understand meteorological and air quality processes. As part of the Bureau of Ocean Energy Management (BOEM) 1998 to 2001 offshore meteorology project, he calculated, evaluated, and analyzed surface fluxes and scaling parameters using the latest techniques developed during the TOGA COARE experiments; characterized the atmospheric boundary layer (ABL); evaluated annual, seasonal, and diurnal variations in the ABL structure; described processes that influence ABL structure and variations in the Gulf of Mexico; and developed a three-dimensional diagnostic wind field to perform transport and dispersion analyses. Mr. MacDonald has also performed a wide range of data analysis activities for other studies, such as the 1996 and 1997 Paso del Norte Ozone Studies, the Kansas City Scoping Study, the San Antonio Ozone Study, the Northern Front Range Air Quality Study, and the NARSTO Northeast 1995 Study.

Selected Publications

Knoderer C.A. and MacDonald C.P. (2013) Summary of data quality control of data collected by four 915-MHz RWP stations for DISCOVER-AQ Houston, from August 22 through October 22, 2013. Technical memorandum prepared for the University of Texas at Austin by Sonoma Technology, Inc., Petaluma, CA, STI-913045-5831-TM, November 21.

Pasch A.N., MacDonald C.P., Gilliam R.C., Knoderer C.A., and Roberts P.T. (2011) Meteorological characteristics associated with $PM_{2.5}$ air pollution in Cleveland, Ohio, during the 2009-2010 Cleveland Multiple Air Pollutants Study. *Atmos. Environ.* 45, 7026-7035 (STI-909032-3910). doi: 10.1016/j.atmosenv.2011.09.065. Available on the Internet at http://www.sciencedirect.com/science/article/pii/S1352231011010284.

Scheffe R., Philbrick R., MacDonald C.P., Dye T.S., Gilroy M., and Carlton A. (2009) Observational needs for four-dimensional air quality characterization. *Air & Waste Manag. Assoc.'s EM*, October 2.

MacDonald C.P. and Knoderer C.A. (2008) Spatial and temporal characteristics of winds and mixing during TEXAQS-II. Final report prepared for Texas A&M University, College Station, TX by Sonoma Technology, Petaluma, CA, STI-907101-3344-FR, April.

Knoderer C.A. and MacDonald C.P. (2007) TEXAQS-II radar wind profiler, Radio Acoustic Sounding System, solar, and lidar data quality control and mixing height derivation. Final report prepared for Texas A&M University, College Station, TX, by Sonoma Technology, Inc., Petaluma, CA, STI-907100-3215-FR, August.

Hanna S.R., MacDonald C.P., Lilly M., Knoderer C.A., and Huang C.H. (2006) Analysis of three years of boundary layer observations over the Gulf of Mexico and its shores. *Estuarine, Coastal and Shelf Science* **70**, 541-550.

MacDonald C.P., Knoderer C.A., and Blumenthal D.L. (2006) Development and implementation of offshore meteorological systems to support TexAQS-II. Final report prepared for the Texas Commission on Environmental Quality, Austin, TX, by Sonoma Technology, Inc., Petaluma, CA, STI-905060-2993-FR, June.

MacDonald C.P. and Lilly M.R. (2003) Making better use of RWP/RASS data. Presented at the *Radar Development and Applications Workshop, NCAR (National Center for Atmospheric Research), Boulder, CO, April 23-25* (STI-2353).

MacDonald C.P., Dye T.S., and Lilly M.R. (2003) Profiler observations, applications, and analysis: techniques that use Profiler/RASS data to characterize meteorological phenomena for use in air quality data analysis and forecasting. Presented at the *American Meteorological Society Short Course on the Fundamentals of Boundary Layer Wind and Temperature Profiling using Radar and Acoustic Techniques, Long Beach, CA, February 9-13* (STI-2320).

MacDonald C.P., Roberts P.T., Main H.H., Dye T.S., Coe D.L., and Yarbrough J. (2001) The 1996 Paso del Norte Ozone Study: phenomena that influence the local ozone concentrations. *Sci. Total Environ.* (Special Issue: U.S.-Mexico Transboundary Air Pollution Studies) **276**, Nos. 1-3, 93-110 (STI-1949).

MacDonald C.P., Dye T.S., and Roberts P.T. (2001) Spatial and temporal observations of the planetary boundary layer during ozone episodes in Southern California. Presented at *SCOS97-NARSTO Data Analysis Conference, Los Angeles, CA, February 13-15* (STI-2057).

Dye T.S., MacDonald C.P., and Roberts P.T. (1999) Mixing depths for air quality applications. Presented at the National Oceanic and Atmospheric Administration Laboratories Cooperative Research and Development Agreement: First European Conference for Atmospheric Wind and Temperature Profiling, Innsbruck, Austria, July 23-24 (STI 999012-1903).

Dr. Gary A. Morris – Co-Principal Investigator

Associate Dean of Arts & Sciences, Professor of Physics & Astronomy, Valparaiso University

(a) Professional Preparation

Washington University	Physics, Mathematics	1989 (AB)
Rice University	Space Physics & Astronomy	1992 (MS), 1995 (PhD)
NASA GSFC	NRC Post-Doctoral Fellowship	1994 – 1997

(b) Professional Appointments

Associate Dean (2010 – present), Professor (2013 – present), Associate Professor (2006 – 2013), Assistant Professor (2004 - 2006), Visiting Assistant Professor (1998 – 2000) of Physics & Astronomy, Valparaiso University.

Adjunct Professor (2012 – present) of Earth & Atmospheric Sciences, Visiting Assistant Professor (2008) of Geosciences, University of Houston.

Adjunct Assistant Professor (2004 – 2007), Wiess Instructor (2000 – 2004), Clinical Assistant Professor (2000 – 2004), and Faculty Fellow (2004) of Physics & Astronomy, Rice University.

Intermittent Research Assistant Scientist, Goddard Earth Sciences and Technology (GEST) Center, University of Maryland Baltimore County, 2003 – 2006.

Research Assistant Professor, Joint Center for Earth Systems Technology, University of Maryland Baltimore County, 1997 – 1998.

(c) Recent Relevant Publications

1. *Stauffer, R.M.*, **G.A. Morris**, A.M. Thompson, E. Joseph, and G.J.R. Coetzee, Propagation of radiosonde pressure sensor errors to ozonesonde measurements, *Atmos. Meas. Tech. Discuss.*, 6, 7771 – 7810, 2013.
2. **Morris, G.A.**, G. Labow, H. Akimoto, M. Takigawa, M. Fujiwara, F. Hasebe, J. Hirokawa, and T. Koide, On the use of the correction factor with Japanese ozonesonde data, *Atmos. Chem. Phys*. *Discuss.*, *12*, 15,597 – 15,638, 2012; *Atmos. Chem. Phys*., *13*, 1243 – 1260, 2013.
3. Haman, C.L., B. Lefer, and **G.A. Morris**, Seasonal variability in the diurnal evolution of the boundary layer in a near coastal urban environment, *J. Atmos. Ocean. Tech*., 29 (5), 697 – 710, 2012.
4. Tang, W., D.S. Cohan, **G.A. Morris**, D.W. Byun, W.T. Luke, Influence of vertical mixing uncertainties on ozone simulation in CMAQ, *Atmos. Environ.*, 45 (17), 2898 – 2909, 2011.
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(d) Synergistic Activities

1. Principal Investigator of Mathematics and Science Education Enrollment and Development (MSEED) Program, a 5-year, $500,000 NSF-sponsored program to enhance STEM enrollments at undergraduate institutions through enhanced training of the next generation of middle and high school math and science teachers.

2. Fulbright Scholar (Japan, Hokkaido University, Sapporo and Research Institute for Global Change, Yokohama, 2008 and 2009)

3. Principal Investigator of Tropospheric Ozone Pollution Project (TOPP), a project that has flown more than 500 sondes in the United States, Japan, and Panama with the help of more than 30 undergraduate students. Database online at www.valpo.edu/ozone.

(e) Collaborators and Other Affiliations

a. Collaborators and Co-Editors *(within the last 48 months and not on this proposal):* Dr. Walter Komhyr; Dr. Eric Bucsela; Dr. Russ Dickerson (Univ. of Maryland); Dr. J. Hirokawa (Hokkaido University); Dr. K. Miyagawa and Dr. Y. Kanaya (Research Institute for Global Change, Yokohama, Japan); Dr. T. Koide (Japan Meteorological Agency); Dr. Jay Herman and Mr. Gordon Labow (NASA GSFC); Dr. Christine Haman, Mr. Marc Taylor, Dr. Barry Lefer, and Dr. Bernhard Rappenglueck (Univ. of Houston)

b. Graduate and Postdoctoral Advisors: Dr. Arthur Few, Rice U.; Dr. James Gleason and Dr. Mark Schoeberl, NASA GSFC

4. Prior Support from AQRP

4.1 Ozonesonde Launches from the University of Houston and Smith Point, Texas, in Support of DISCOVER-AQ

Institutions: Valparaiso University (Gary Morris, PI) and the University of Houston (Barry Lefer, PI)

Funding was received in FY12-13 for 30 ozonesonde launches from the University of Houston and/or Smith Point during August through September 2013, in support of DISCOVER-AQ.

In preparation for the intensive observation period, a training session on preparing, calibrating, and launching ozonesondes was conducted at the University of Houston in July 10 through 13, 2013. Four ozonesondes were launched during the training period.

In August, six ozonesondes were launched, with three launches occurring in mid-August (16, 17, and 19) and three occurring at the end of August (29, 30, and 31).

In September, 22 additional ozonesonde launches occurred, with one additional aborted launch due to an instrument failure, and one launch during which the balloon broke free from the payload. The former could not be resolved, but for the latter, a second balloon was inflated and the launch took place successfully.

All data are posted on the project website: http://physics.valpo.edu/ozone. In addition to the data in text format, there are plots of ozone profiles (in both mixing ratio and partial pressure), temperature, potential temperature, relative humidity, wind speed and direction, and skew T plots. Balloon trajectories can be downloaded into Google Earth for each flight. Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) back-trajectories have been calculated for each flight at 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 km. The website provides links to Unisys weather archives, which include weather maps, infrared satellite images, and upper level air maps for each flight.

Analysis of the large volume of data is ongoing. Early results demonstrate that 2013 was a very unusual year for ozone in Houston, with mid-September profiles more resembling climatological early August profiles. The lack of frontal passages before September 21 influenced the background conditions, affecting the meteorological context for the DISCOVER-AQ mission.

4.2 DISCOVER-AQ Ground Sites Infrastructure Support; Grant 12-004

Subtask: Operation of four Radar Wind Profilers for DISCOVER-AQ

Institutions: University of Texas (Vince Torres). STI subcontracted to the University of Texas. Clinton MacDonald was the PI for the subcontracted work.

STI and NOAA successfully deployed and operated four RWPs in the greater Houston area from August 22 until October 22, 2013, to support NASA's DISCOVER-AQ project. A key goal of DISCOVER-AQ is to improve our ability to use satellite data to diagnose the spatial distribution of air pollution in the atmospheric boundary layer. Better use of satellite data to measure and characterize the processes that influence air pollution requires measurements of boundary layer winds and mixing heights that are provided by RWPs. The RWP wind data are being quality controlled and are expected to be delivered to University of Texas by November 28, 2013. All RWP wind data are posted to a project website. While the RWP data can be used to determine daytime mixing heights, determination of mixing heights and analysis of the boundary layer data are not covered by this grant.

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