Resolving Environmental Atmospheric Profiler (REAP):

Diagnostic for Electro-Optical Sensing, Laser Communications, Hydrology and Agricultural Research

MZA Associates Corporation, 1360 Technology Court, Suite 200, Dayton, Ohio 45430
Contact: Matthew R. Whiteley Ph.D., 937-660-7800, matthew.whiteley@mza.com

MZA's Resolving Environmental Atmospheric Profiler (REAP) offers a new and innovative range diagnostic capability enabling advanced research in electro-optical sensing, laser communications, hydrology, and agricultural applications. The optical, laser, and computer hardware for each REAP measurement terminal unit is shown in Figure 1. When these terminals are placed on each end of a propagation path, the strength of turbulence or index-of-refraction structure coefficient (C_n^2) can be resolved along the line-of-sight between the terminals. These turbulence fluctuations, commonly observed as twinkling of distant lights or stars, have a substantial effect on the performance of high resolution electro-optical (EO) imaging sensors and can reduce efficiency of laser beam projection for illumination and optical communications. The same phenomena also give insight into other aspects of the atmospheric path, including critical evaporation and evapo-transpiration measures important in water and agricultural management activities, especially in arid or semi-arid regions around the world where food and water resources are limited.

Figure 1. Optical, laser, and computer hardware comprising each REAP terminal.

For long horizontal paths over land, turbulence fluctuations due to differential heating of the earth's surface is affected by terrain, wind, vegetation, crops, urban construction, and water features. Figure 2 shows a typical setup for the REAP system as deployed in the field. The REAP laser and optical terminals are placed on each side of a propagation path which can extend from several hundred yards to 25 miles or more given available line-of-sight between the units. The equipment on each end of the path is identical, transmitting multiple laser wavelengths and receiving these signals on the other side through a series of filtered subapertures. An image of each laser is formed, recorded, and processed with sensitive cameras which record the deviation or "dancing" of each laser and its intensity fluctuation. These measurements are processed into key quantities which are communicated bi-directionally using built-in wireless communications (or internet capability, if available.) The unique geometry of the REAP system enables resolution of changes in turbulence along the path resulting from the surface features along that path. The REAP processing also allows for estimation of cross-wind speeds as seen from both sides of the path—another critical atmospheric characteristic. The REAP system can automatically collect, process, catalog, and report these data for future reference.

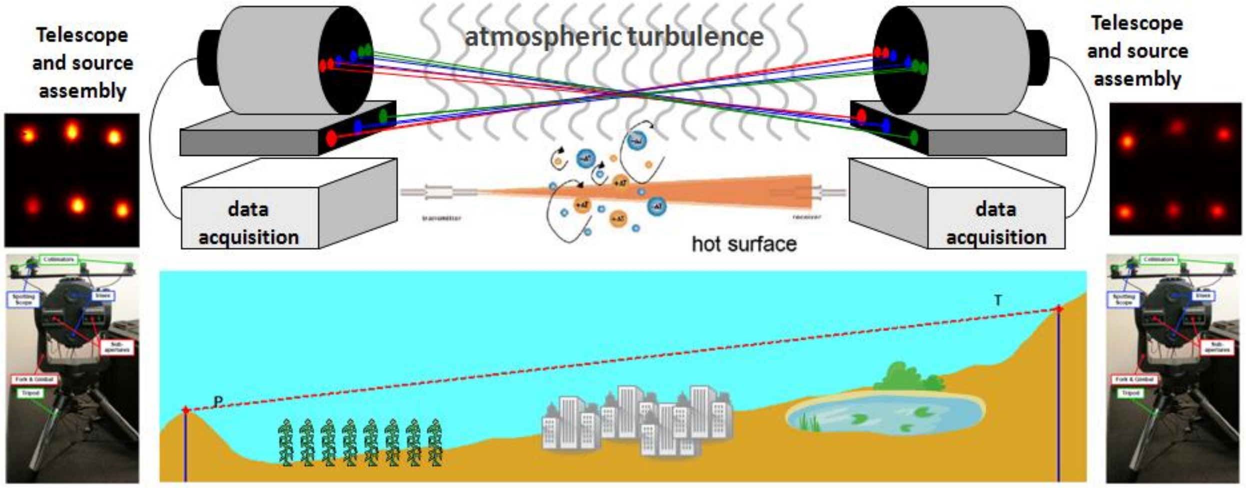


Figure 2. REAP terminals placed at each end of the path measure optical turbulence resulting from differential surface heating as affected by terrain, crop/vegetation, urban buildings, and water features.

MZA's REAP system has been deployed for field measurements in the past year and is actively supporting advanced laser sensing and beam control tests for DoD research. Figure 3 (top) shows an example of the type of measurements reported from a REAP system operating over a 2-mile path for a 48 hour period. These plots show a time history of the C_n^2 measurements resolved along the path into approximately 100 m segments. The logarithmic color scale highlights the substantial diurnal (horizontal axis) and spatial variation (vertical axis) in turbulence strength observed over this path. It is apparent from these data that the C_n^2 along the path must be resolved in multiple measurements over the path to obtain an accurate turbulence diagnostic over the line-of-sight.

Figure 3 (bottom) shows a comparison of a path-averaged value from the REAP system compared with 2 separate large-aperture scintillometers (LASs) operating in the same area. Unlike REAP which reports 30-40 C_n^2 values along the path, the LAS systems report only a single value. The data in Figure 3 (bottom) shows that the REAP data when averaged over the path gives the same fundamental diagnostic of turbulence conditions as these LAS systems. However, the REAP provides a path resolution capability that is not available with a LAS-type system. Therefore, REAP offers more than 10x the measurement capability of a typical LAS.

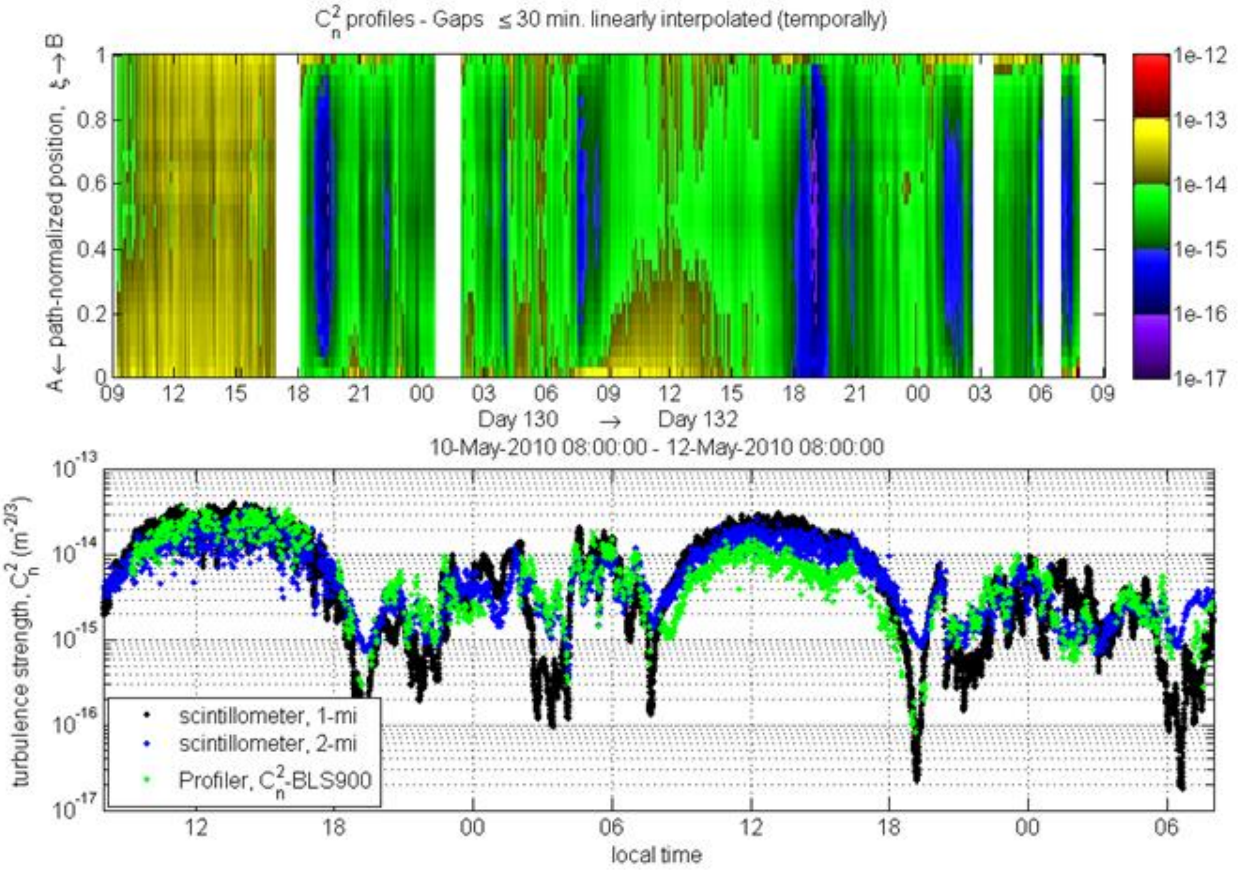


Figure 3. (Top) Time history of REAP turbulence measurements over a 2-mile path showing significant diurnal and spatial variation of turbulence. (Bottom) Path-averaged turbulence strength from REAP profiles compared with accompanying large-aperture scintillometer measurements.

Currently, there is wide-spread interest in the use of LAS systems for environmental science applications. In particular, LAS techniques are finding a growing use in hydrology studies for large scale water management projects. The LAS devices which measure a path-averaged C_n^2 can be used to estimate the amount of water loss occurring over a large land area through evaporation mechanisms—which are the largest source of water depletion. These water management projects are especially important for arid or semi-arid regions where water resources are limited and must be monitored closely. While there are many activities underway to monitor evaporation through use of satellite imagery, these methods still depend on direct atmospheric measurement devices to provide the necessary calibration to make the satellite data useful. Because of the limited resolution and field-of-view capabilities of satellite systems, LAS field measurements are increasing important for wide-scale water resource management.

MZA's REAP diagnostic system offers a capability to drastically improve the water resource management process through path-resolved turbulence strength monitoring. The REAP can pinpoint regions of high or low turbulence strength within a certain portion of the path which indicate differences in water depletion owing to changes in landscape, vegetation, winds, solar heating, etc. For instance, whereas a typical LAS could give a single turbulence measurement that is averaged over 3000-5000 meters, MZA's REAP system can provide C_n^2-derived evaporation measures over 30-50 meter increments—the size of a typical structure, feature, or vegetative change. Figure 4 shows examples of these small-scale measurements of turbulence strength collected over a 2-mile path. Whereas a LAS system would have read the path at a single value, the REAP shows quite a change in turbulence strength along the path, principally related to changes in terrain in this case.

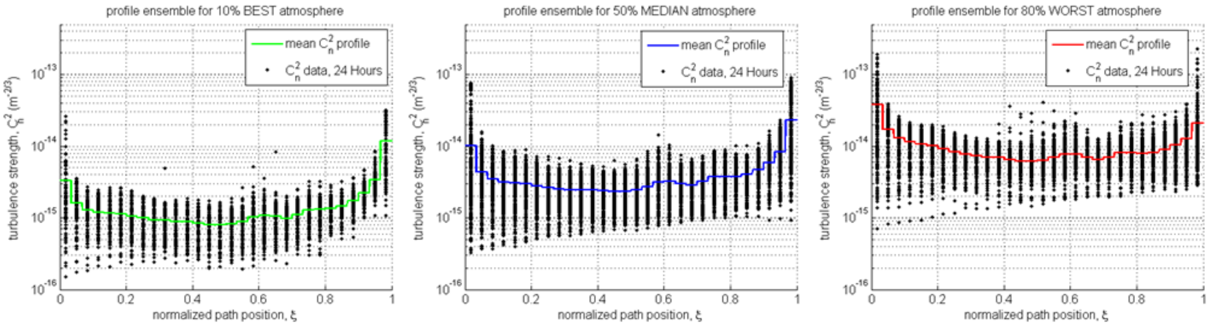
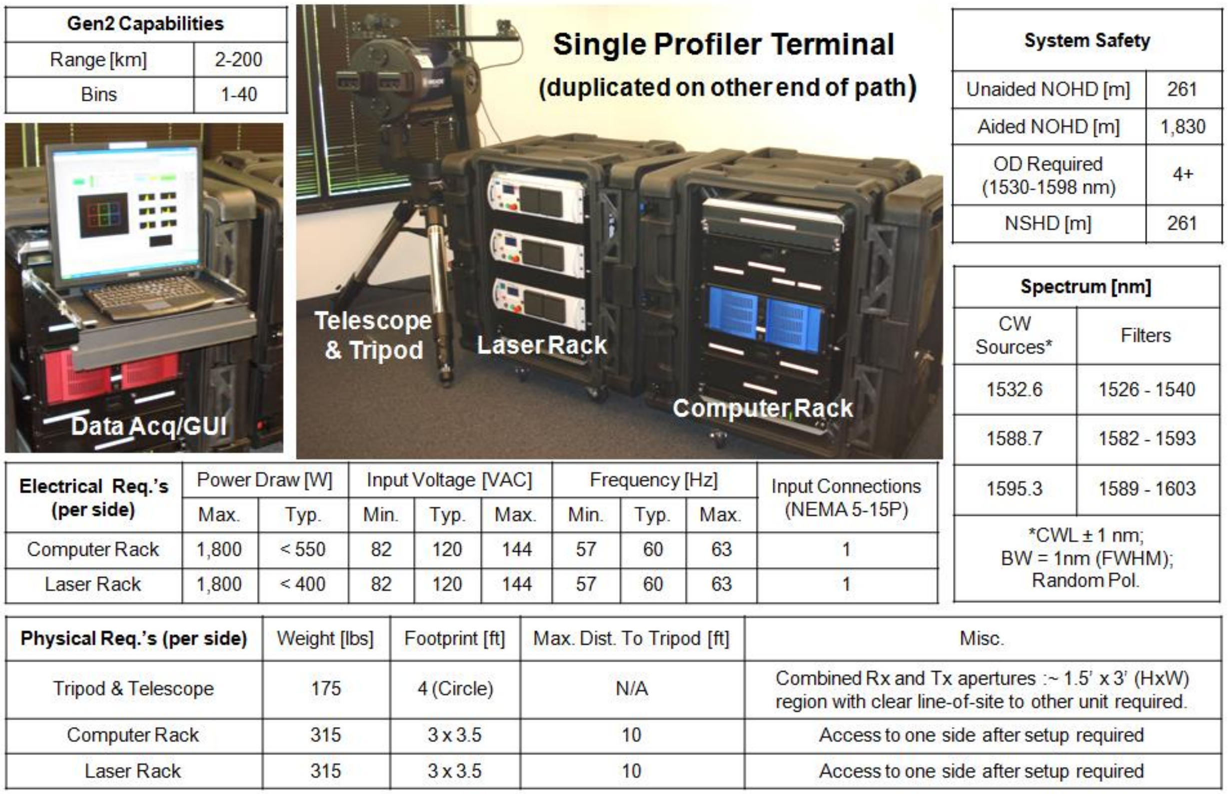


Figure 4. Ensemble of REAP measurements for low (left), medium (center), and high (right) turbulence.

Aside from hydrology and water resource management, the REAP system can be used for agricultural development purposes as well. In order to provide food resources in regions where water supplies are limited, the REAP could be used to closely monitor large-scale field conditions in order to control irrigation resources on a schedule that takes the guess-work out of problem. Grain, wheat, or corn field irrigation could be regulated based on the REAP-derived evaporation rates. In the area of agricultural research, bio-engineered crops could be developed and tested in order to conserve precious water resources. MZA's REAP system could be used to sow only as much crop as can be reasonably sustained, and to reap the food resources so vitally in demand for developing countries.

In addition to manufacturing of the REAP hardware to support laser, optical, hydrology, and agriculture programs, MZA offers services for turbulence measurements using the REAP system. For start-up efforts, field support from MZA's REAP measurement service may be the most cost-effective solution to providing the needed information at good cost point. The operating specifications of the REAP hardware are detailed below in Figure 5. The system is designed to be transportable and can be packed into a typical SUV for operation in the field. The REAP system supports a wide range of measurement lengths reaching out well over 100 miles with proper line-of-sight and atmospheric visibility. The REAP turbulence data can be used directly in MZA's WaveTrain wave-optics simulation tools to quantify the impact of the measured disturbances on optical systems. MZA is also a premier provider of adaptive optical (AO) systems for compensation of atmospheric turbulence. Therefore, having established a baseline of conditions over a certain propagation path, we can tailor and adaptive optics system capability that is well-suited for the need. This is useful for high-bandwidth point-to-point laser communications where a high-quality optical link is desired to sustain operations over a wide range of atmospheric conditions. Without the insight provided by MZA's REAP system, laser communications will be less reliable, especially in urban environments where laser propagation is affected by buildings, concrete, and vegetative mix.



Gen2 Capabilities	
Range [km]	2-200
Bins	1-40

System Safety	
Unaided NOHD [m]	261
Aided NOHD [m]	1,830
OD Required (1530-1598 nm)	4+
NSHD [m]	261

Spectrum [nm]	
CW Sources*	Filters
1532.6	1526 - 1540
1588.7	1582 - 1593
1595.3	1589 - 1603
*CWL ± 1 nm; BW = 1nm (FWHM); Random Pol.	

Electrical Req.'s (per side)	Power Draw [W]		Input Voltage [VAC]			Frequency [Hz]			Input Connections (NEMA 5-15P)
	Max.	Typ.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Computer Rack	1,800	< 550	82	120	144	57	60	63	1
Laser Rack	1,800	< 400	82	120	144	57	60	63	1

Physical Req.'s (per side)	Weight [lbs]	Footprint [ft]	Max. Dist. To Tripod [ft]	Misc.
Tripod & Telescope	175	4 (Circle)	N/A	Combined Rx and Tx apertures :~ 1.5' x 3' (HxW) region with clear line-of-site to other unit required.
Computer Rack	315	3 x 3.5	10	Access to one side after setup required
Laser Rack	315	3 x 3.5	10	Access to one side after setup required

Figure 5. Hardware and operating specifications for the REAP diagnostic system.