# Large Aperture Scanning Lidar based on Holographic Optical Elements

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***Abstract-* We have developed simplified conical scanning telescopes using Holographic Optical Elements (HOEs) to reduce the size, mass, angular momentum, and cost of scanning lidar systems. This technology enables wide-angle scanning and three-dimensional measurements of atmospheric backscatter when used in airborne instruments, and high temporal resolution observations of atmospheric dynamic structure, including wind profiles from ground-based facilities.**

## I. INTRODUCTION

Lidar remote sensing instruments can make a significant contribution to satisfying many of the required measurements of atmospheric and surface parameters for future spaceborne platforms, including topographic altimeters, atmospheric profiles of, wind, humidity, temperature, trace molecules, aerosols, and clouds. It is highly desirable to have wide measurement swaths for rapid coverage rather than just the narrow ribbon of data that is obtained with a nadir only observation. For most applications global coverage is required, and for wind measurements scanning or pointing is required in order to retrieve the full 3-D wind vector from multiple line-of-sight Doppler measurements. Conventional lidar receivers make up a substantial portion of the instrument's size and weight. Wide angle scanning typically requires a large scanning mirror in front of the receiver telescope, or pointing the entire telescope and aft optics assembly. Either of these methods entails the use of large bearings, motors, gearing and their associated electronics. Spaceborne instruments also need reaction wheels to counter the torque applied to the spacecraft by these motions. NASA has developed simplified conical scanning telescopes using Holographic Optical Elements (HOEs) to reduce the size, mass, angular momentum, and cost of scanning lidar systems [1].

## II. SCANNING HOLOGRAPHIC TELESCOPE

An HOE is a hologram of a point source, constructed by the interference between monochromatic light from a point source and a collimated reference beam. In use, it is illuminated with light sources identical or conjugate to either of the construction beams and will reproduce the other corresponding source. If illuminated with a diverging laser beam similar to the original point source, it will produce a collimated beam upon diffraction through the HOE. From a collimated or quasi-collimated source it reconstructs a real image of the original point source. We utilize both configurations in a lidar, where the HOE serves as the transmitting laser's collimating lens as well as the receiver's collecting aperture (Fig. 1). The laser beam is directed through a diverging lens that is f-matched to the focal length of the HOE. The beam is then steered using fixed mirrors to a line normal to and through the center of the HOE, which collimates and directs the beam out the other side at the desired scan angle. Rotating the HOE in its own plane scans the transmitted laser beam around in a cone. Backscattered

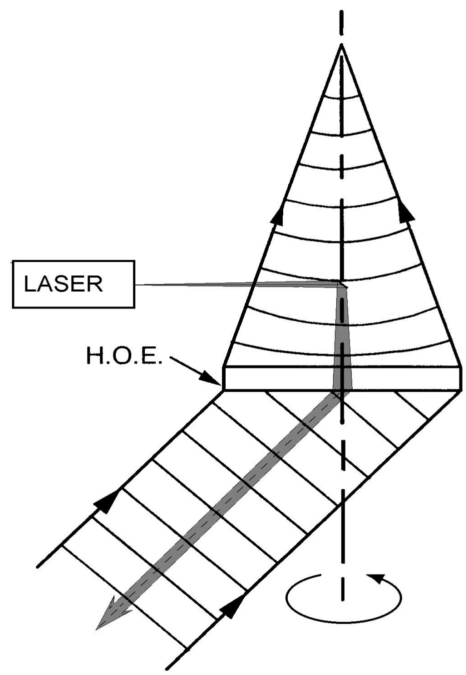


Fig. 1. Concept for a HOE scanning telescope.

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laser light is collected by the entire HOE aperture and brought to a focus back on axis, as represented by the parallel lines representing optical wavefronts in Fig. 1.

There are two general types of HOEs – transmission (as in Fig. 1) and reflection HOEs, in which the incident and diffracted beams are on the same side of the film. Each has specific advantages and disadvantages, and we have investigated both types.

NASA has developed two operating lidar systems using 40 cm diameter HOEs. The first such system was a joint development between NASA Goddard Space Flight Center (GSFC) and the University of Maryland College Park [2]. This lidar is based on a reflection HOE for use at the doubled Nd:YAG laser wavelength of 532 nm and was subsequently named Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS), having undergone a number of design changes in a collaborative effort between GSFC and Saint Anselm College in New Hampshire [3].

We then developed IR transmission HOEs for use with the Nd:YAG fundamental and successfully employed one in the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) [4]. In both PHASERS and HARLIE, the HOE diffracts ~85% of the incident light at the laser wavelength, and on the receiver side focuses the backscatter into a 200-micron diameter optical fiber placed in the focal plane. The fiber is used to carry the light to an optics package that filters out background light and directs the optical signal to a photon counting detector. Both systems have scan angles of ~45°. They are used for measuring aerosol and cloud backscatter profiles. HARLIE has flown several times in a down-looking orientation and is also used from a ground-based trailer in an upward-looking mode.

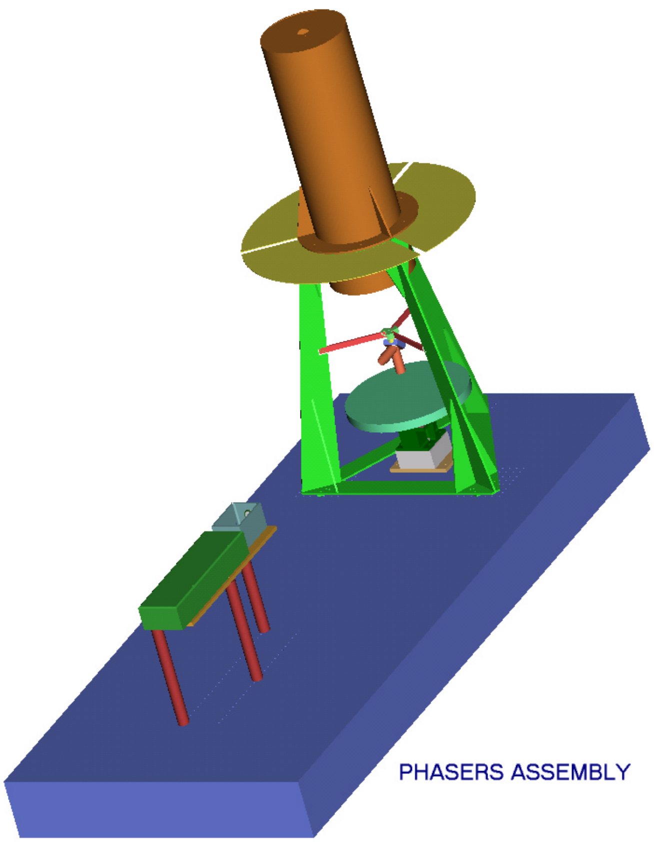


Fig. 2. Drawing of the PHASERS lidar. The HOE is the disk at the bottom of the tripod assembly. The laser is the box in the foreground.

## III. LIDAR MEASUREMENTS

This new technology has also presented us with new data visualization challenges as well as new measurement techniques. In a moving platform such as an airplane or satellite, the data from consecutive scans cover different areas under the flight path, revealing atmospheric structure in three dimensions. The backscatter data obtained from a stationary (i.e. ground-based) location, when viewed over many consecutive scans, reveals atmospheric motions over a conical surface as the atmosphere advects over the site. Fig. 3 is one example of a visualization of HARLIE ground-based data, showing aerosol backscatter on a 90-degree conical surface generated in 36 seconds over a single 360º scan of the lidar during the HOLO-1 field campaign on the afternoon of 10 March 1999. Higher backscatter levels are rendered as light colored structures against a dark background and act as tracers of atmospheric structure and motion. Breaking Kelvin-Helmholtz waves are evident on the north side of the scan at an altitude of 10-11 km.

Time series of successive scans made at regular intervals render unique views of atmospheric motions, from which we

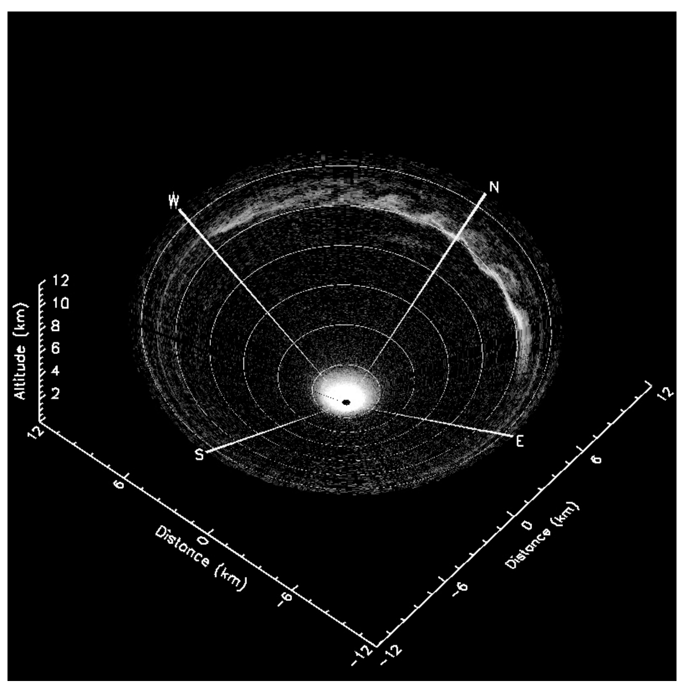


Fig. 3. Visualization of atmospheric aerosol lidar backscatter over one conical scan. Each circular grid line on the cone represents an increase of 2 km in altitude and horizontal radius.

have obtained vertical profiles of atmospheric wind vectors using a unique data analysis approach. Wind vectors retrieved with the lidar are compared with co-located rawinsonde wind profiles during an intensive operating period in September-October 2000 at the Atmospheric Radiation Measurement Program's Southern Great Plains Central Facility in Fig. 4.

## REFERENCES


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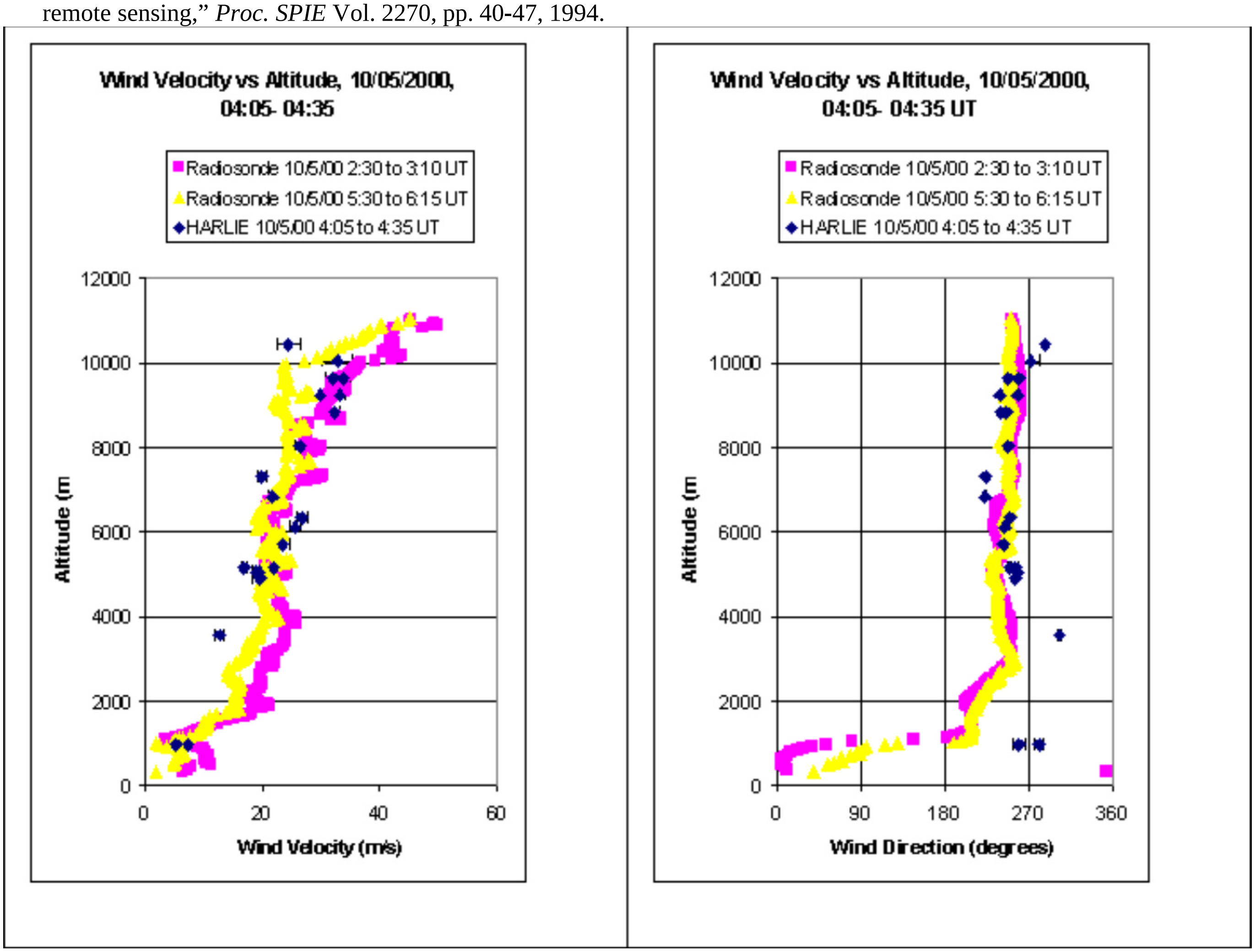


Fig. 4. Plot of HARLIE wind speed (left) and direction (right) measurements (black diamonds), compared with rawinsonde derived winds (yellow triangles and pink squares). The error bars represent the rms of several measurements taken over a 30-minute period.