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A Direct Doppler Detection Lidar System for Atmospheric Winds

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Abstract

A new approach to sensing the wind velocity using Doppler lidar is being developed which promises to improve our measurement capability. Demonstration of this wind lidar will utilize the recently developed equipment prepared under the Laser Atmospheric Measurements Program (LAMP) at Penn State University. Development of the laser atmospheric wind sensor to profile lower and middle atmosphere winds will extend the capabilities of the LAMP instrument. This paper discusses two unique concepts which lead to advances in our ability to measure winds with Doppler lidar. One development is the quad-cavity Fabry-Perot etalon design, which will allow the etalon to simultaneously monitor the wind while under active tuning control. Several measurement campaigns will be carried out to demonstrate the wind sensor system including comparisons with met rockets, passive techniques, and radar. The second development is the use of the seed laser to stabilize the Fabry-Perot etalon continuously. Predicted system performance will be presented.

INTRODUCTION

At present, high resolution middle atmosphere wind measurements are obtained using rocket soundings, mainly by tracking a falling target (Robin sphere). Satellite remote sensing instruments can also provide low resolution wind data. Additionally, MST radars are capable of measurements in regions of aerosol scatter below 20 km, or electron scatter above 60 km during the day and 90 km at night.

Answering critical scientific questions regarding the middle atmosphere depends on more detailed observations of the dynamics of this region. For example, the heating rates caused by gravity wave breaking, and the coupling of momentum flux into the mesosphere from the wave field, and influences the vertical/horizontal transport of minor species are just a few of the important questions to be examined.

Accurate monitoring of the middle atmosphere will have more direct application to weather forecasting and lower atmospheric modeling since it couples the upper and lower atmospheric regions through influences of the global atmospheric circulation patterns. Additionally, dynamical and chemical data rely on a climatological description of the wind field. The recent developments of coupled models such as the TGCM[1], show the importance of describing the interaction between the waves and the general circulation patterns to explain global response to the increase in IR greenhouse gases. A complete understanding of the processes and a meaningful test of the theories requires simultaneous observations of the wind vector fluctuations throughout the middle atmosphere.[2] The wind sensor will be used to characterize lower and middle atmospheric dynamics. Previously unattainable data on the dynamics should allow advances in modeling efforts and weather prediction.

Lidar provides high temporal and spatial resolution which is required for dynamic studies. Several research groups have built lidar wind sensors.[3,4,5] However, some systems are unable to maintain measurement stability of the detected wavelength or cannot accurately measure winds due to lack of aerosols above 20 km. The planned system, which is capable of high resolution wind measurement in the lower and middle atmosphere has been modeled. Two innovations which have been incorporated into the design and tuning of the Fabry-Perot etalon should allow accurate measurement of the lower and middle atmosphere winds.

INSTRUMENT DESCRIPTION

In the absence of wind, air molecules have a speed that is proportional to temperature. In any direction, the molecules have a speed distribution as shown in Figure 1a. This distribution becomes the Maxwellian velocity distribution if all speed components are integrated along one axis as shown in Figure 1b. Illuminating this volume with a laser results in a Doppler broadening of the laser pulse with the same distribution as the molecular velocities.

If there is no wind present, the curve shown in Figure 1b will remain unchanged. However, if there is wind present, the entire curve will be shifted in the direction of the radial wind. It is this shift that we wish to measure.

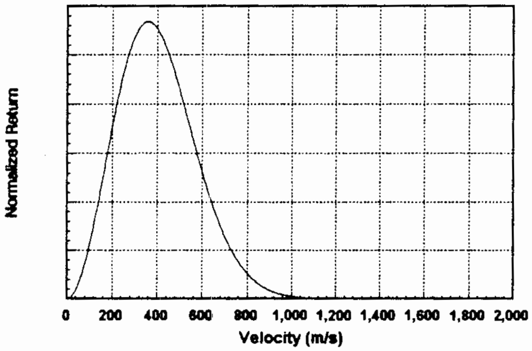

Figure 1a -- Molecular Speed Distribution

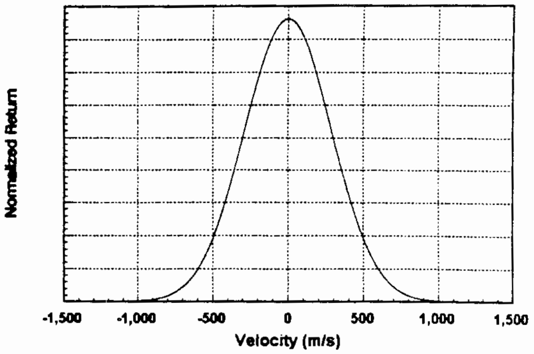

Figure 1b -- Maxwellian Velocity Distribution

The key measurement element of the proposed wind sensor system is a quad-cavity Fabry-Perot etalon. This F-P uses several new concepts in optical coating and etalon tuning technology. The step etalon plate is shown in Figure 2. A standard quartz etalon plate has a layer of quartz deposited over one half of the surface to produce a consistent interface with a step which determines the shift of the passband from the laser center wavelength. This plate is then finished with a standard etalon coating. If the opposite plate of the etalon is flat, this configuration permits simultaneous tuning to two different wavelengths.

If both plates are stepped with identically coated plates and rotated 90 degrees with respect to each other, then four different cavities are formed as shown in Figure 3. The two cavities of the same length, one side is stepped and the other side not stepped, are the reference cavities. If these reference cavities are tuned to the laser wavelength, the shorter and longer cavities are then tuned to the short and long half power points, respectively.

The configuration uses the seed laser for the primary laser oscillator to produce the very narrow line width (< 80 MHz) signal required. By directing a portion of the seed laser output through the

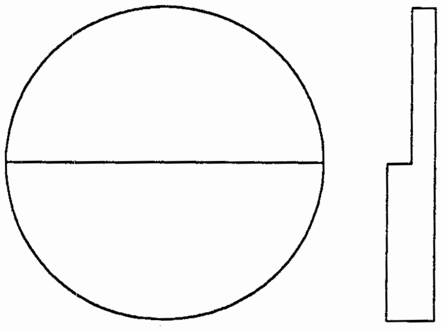

Figure 2 -- Etalon plate showing the step increase in the thickness of the plate.

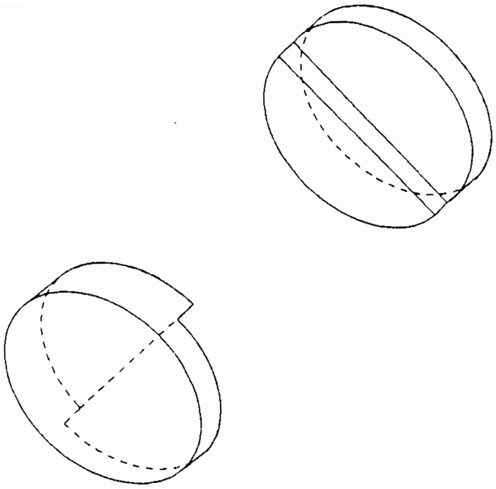

***Figure 3** -- Rotated etalon plates showing quad-cavity configuration.*

reference cavities, the etalon can be continuously optimized to the laser wavelength. Since the wavelength of the seed laser (1064 nm) is exactly double the wavelength of the laser output (532 nm), when the cavities are optimized to the seed laser, the etalon will be optimized to the half power points of the final laser output as shown in Figure 4.

Using one quad-cavity F-P, the wind velocity vector can be accurately measured. The measurement is accomplished by calculating the ratio of the two transmitted half power passband signals, which is directly related to the radial component of the wind velocity. If the wind velocity is toward the instrument, the center frequency of the Doppler broadened pulse will increase, which results in an increase in the intensity transmitted through the shorter cavity and a decrease in the intensity through the longer cavity. The opposite is true if the radial component of the wind is in the same direction as the beam. The ratio of the intensity measured at the two cavities thus provides the measure of the wind velocity.

The horizontal wind velocity component can be determined from the radial wind velocity by taking two separate measurements in orthogonal directions assuming that the vertical component is negligible. In some applications it is important to determine the vertical wind velocity, however since the vertical component of the wind is typically an order of magnitude or more smaller than the horizontal component, it can be neglected in the preliminary analysis. The initial design includes four orthogonal measurements thereby, 1) allowing vertical wind determination using three independent direction measurements, and (2) allowing for an overly determined wind velocity vector.

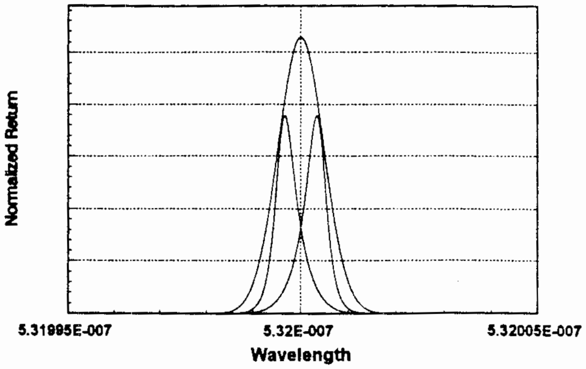

***Figure 4** -- Etalon passbands over thermally broadened laser pulse.*

PREDICTED SYSTEM PERFORMANCE

Using results obtained from the LAMP lidar with an integration time of approximately 30 minutes and a range bin of 120 meters, initial calculations yield a 1 m/s velocity resolution at 30 km. As a result, this wind sensor design should be capable of wind measurements to altitudes above 50 km with reasonable integration times. If higher altitude measurements are desired, the system is easily adaptable to a larger class of telescope and laser system.

The development of the wind sensor system including testing and intercomparisons will take place over a two year period. The first year, which will be devoted primarily to system preparation and testing, includes: manufacture of the Fabry-Perot etalon, modifications to LAMP, and initial testing with comparisons to weather balloons. The second year includes further testing and a proposed comparison with met rocket data at the NASA launch facility at Wallops Island, Va., and at Fairbanks, Alaska. The campaigns includes data matching with passive optical instruments, rocket launches, and radars.

CONCLUSION

While there are some limited data on the middle atmosphere, it still remains largely unmonitored. By using several innovative techniques, a new method for Doppler lidar measurements of the middle atmosphere has been suggested. The system allows for wind measurement in the lower and middle atmosphere using a two new concepts. The use of the seed laser permits the required 1 MHz reference accuracy to measure wind, and the stepped etalon both will be major advantages. Other measurements also benefit from this development including more accurate temperature profiles obtained in the lower atmosphere since this system is not as susceptible to the aerosol scattering as are other molecular scatter (elastic) lidars.

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