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Early Observations of the Middle Atmosphere Above USU With the World's Most Sensitive Lidar

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Abstract

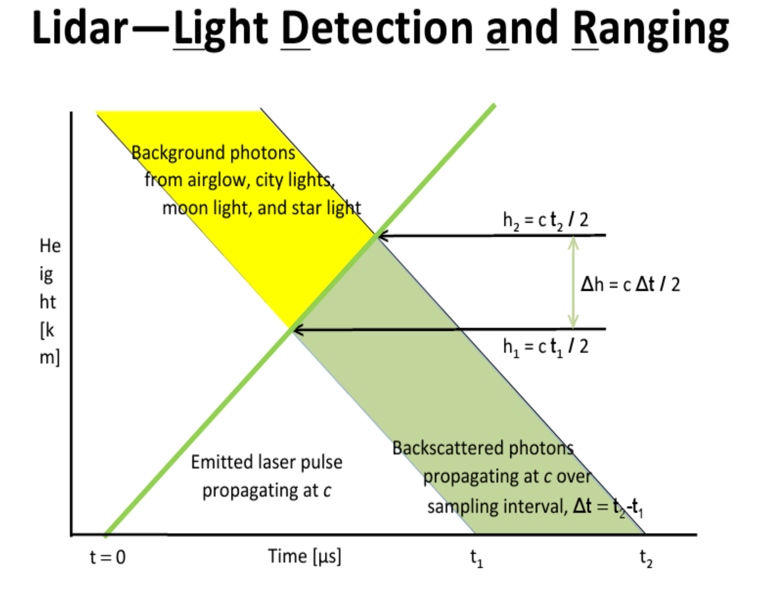
Extensive measurements have been made of the upper atmosphere by satellites and the lower atmosphere is measured twice daily by weather balloons. In contrast, the middle atmosphere is a difficult area to measure and therefore has been much less extensively studied. We are currently upgrading an old lidar system to a new system that will be 70 times more sensitive, making this the most sensitive lidar of its kind in the world. The upgrade consists of combining the outputs of 18 and 24 watt Nd:YAG lasers; implementing an optical chain to detect backscattered light using an existing large, four-mirror telescope; four optical fibers; an optical system and mechanical chopper; photomultiplier tubes; a data-acquisition system; and an aircraft detection radar. Moving to this new system will allow us to extend Rayleigh-scatter observations from 90 to 110 km in the mesosphere and lower thermosphere, significantly higher than was possible with the original system. Alternatively, it will enable significantly greater precision or better time resolution for observations in the previous altitude range. After finishing the upgrade, we will use software previously designed for this system to perform the reduction and analysis of the first data to obtain relative density fluctuations and absolute temperatures.

Introduction

Lidar stands for Light Detection and Ranging. In our system, a laser is used to send short pulses of photons at 532 nm into the atmosphere. Some of these photons are scattered back down by the molecules and particles in the air. This return signal is collected by 4 large (1.25 m diameter) mirrors which focus the light into fiber optic cables. These fibers are then used to transport the signal down to a Photomultiplier Tube (PMT) in our lab.

This method measures the number of photons that returned to the detector in specified time bins. Due to the speed of light being constant, we are able to know which altitude range each time bin corresponds to. The number of backscattered photons is proportional to atmospheric density. This allows us to compile a profile of the relative density.

Lidar—Light Detection and Ranging



USU's 4-Mirror Lidar Telescope

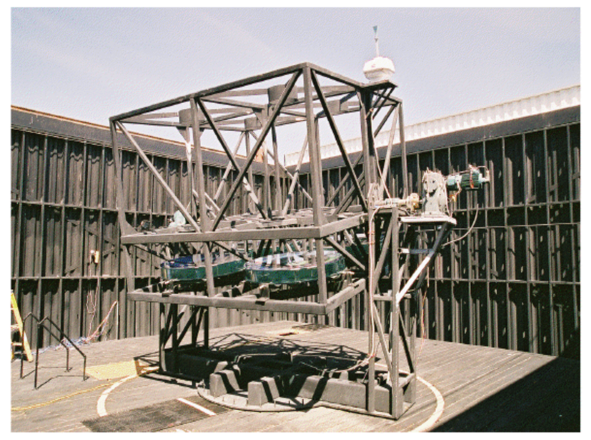


Photo by Vincent Wickwar

The density of the atmosphere is proportional to the temperature, thus we can determine the temperature from the slope of the density as a function of altitude. The slope of that line is independent of the actual density, so the derived temperatures are absolute and require no calibration. More specifically, we combine the ideal gas law and hydrostatic equilibrium to determine the temperatures.

Upgrade

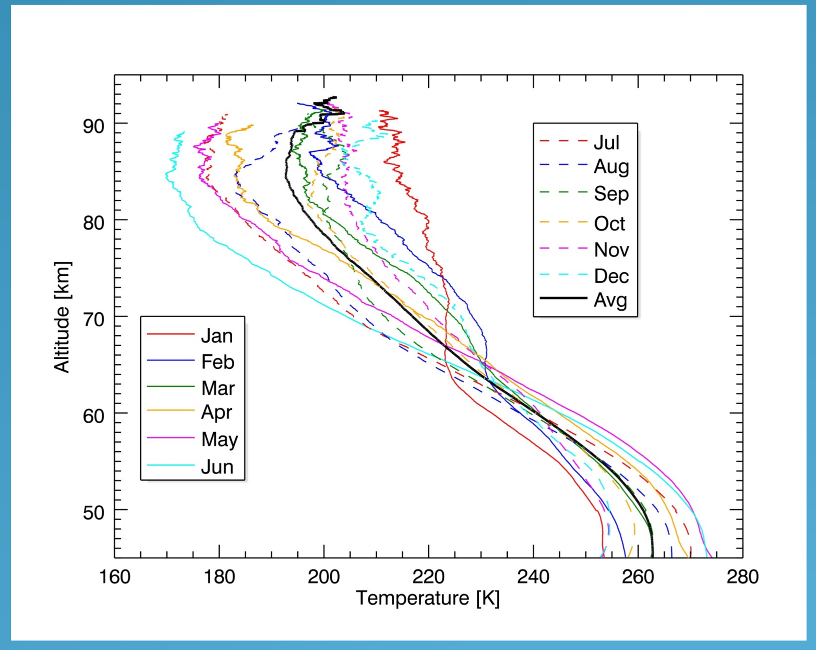
We have been in the process of upgrading our lidar system. This upgrade has included using two Nd:YAG lasers, 4 large mirrors, and some new optical components. This will make the USU ALO lidar the most sensitive one of its kind in the world.

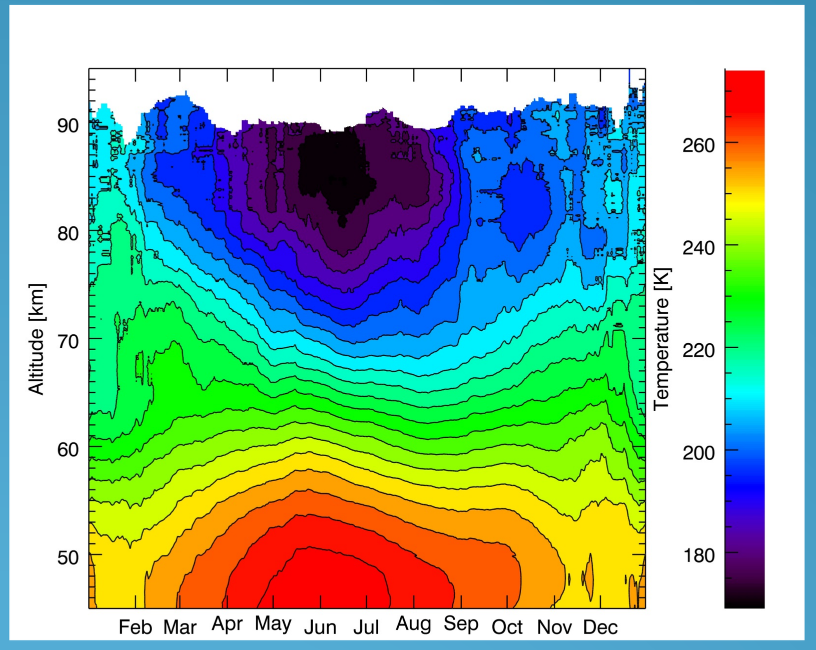
Power-Aperture Product is a measure of the sensitivity of a lidar. It is the product of the laser power and the telescope collecting area and is measured in Wm^2.

- Original lidar (18 & 24 W lasers) : **2.7 Wm^2** **3.6 Wm^2**
- 4-Mirror lidar (18 & 24 W lasers) : **88 Wm^2** **117 Wm^2**
- 4-Mirror lidar (both lasers) : **205 Wm^2**

Results

Due to difficulties with upgrading the lidar and perpetually cloudy weather, we have not yet been able to obtain useable data with the new system. These are results from the previous version of the lidar and are representative of the type of data obtained by the ALO lidar and the analysis used.





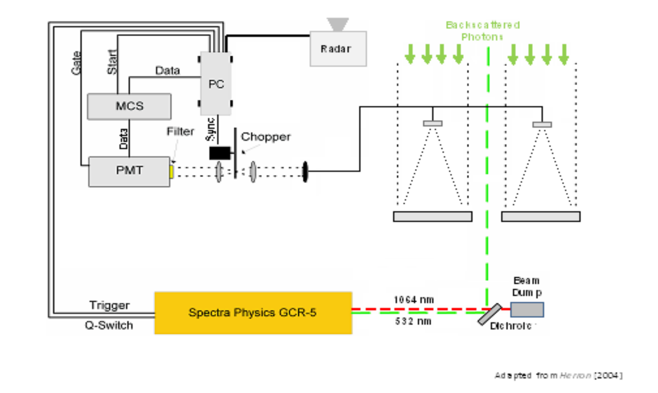
Implementation

This upgrade has spanned several years of work due to difficulties with funding. This last year has primarily focused on 3 areas: the timing system, alignment of the beam, and arranging optical components.

The timing system is run by a LabVIEW program which coordinates the optical chopper, the flash lamps and Q-switching of the laser, the PMT, the photon counter, and a radar for airplane detection. This system need to be modified to accommodate the second laser, to control the Q-switching, to have the radar switch the lasers off when a plane is detected, and to work with a different PMT.

The beam alignment is accomplished by two stepper motors attached to the final mirror on the optical bench, which directs the laser upwards. These stepper motors allow us to direct the beam until it is vertical. Testing how nearly vertical the beam is includes comparing the beam to the surrounding buildings.

Block Diagram of Lidar System



The optical components include the dichroics, beam expander, mirrors, optical fibers, lenses, interference filter, and PMT. The challenge of arranging the optical chain before the lasers are directed upwards is increased because of the power of these lasers.

Future Work

There are many different scientific questions that can be explored using this instrument. Some of these studies include:

- Propagation of gravity waves
- Tides
- Solar cycle variations
- Long-term trends
- Noctilucent clouds
- Exploring the temperature climatology and its variation
- Comparing our technique to those from OH airglow observations
- Comparing our technique with a sodium lidar that was newly relocated to USU

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