Remote Sensing the Upper Atmosphere with Lidar from Space
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Lidar (Liight Detection And Ranging) remote sensing of the atmosphere has now been realized for tropospheric remote sensing of clouds and aerosols on the NASA CALIPSO satellite as part of the A-Train constellation (ref: CALIPSO:Link). NASA also demonstrated cloud lidar on the Space Shuttle with the LITE experiment (ref: LITE:Link). NASA has invested and developed lidar systems for tropospheric observations, successfully. Lidar technology is now ready for development and incorporation into Space Science platforms for upper atmospheric/ionospheric remote sensing.

Background: Ground based lidar studies of the upper atmosphere
The Earth’s upper atmosphere (Upper stratosphere and lower mesosphere, 30-75 km) have been studied from ground based observatories with Rayleigh lidars, primarily using 532 and 355 nm transmitters. Resonance lidar has been used on metals (Na, K, Ca, Ca+, and Fe constituents), all of which reside in a globally distributed layer the 80-110 km altitude region as a result of meteor oblation (See Ground Based LINK to more that 50 globally distributed Rayleigh LIDARS). A study by the NSF Coupling of Energetic and Dynamic Atmospheric Regions (CEDAR) community summarizes a compilation of scientific accomplishments, effective 2005, by the CEDAR:LIDAR committee as reported in (ref: CEDAR: LIDAR). The resonance LIDARS are primarily Doppler systems, measuring winds and temperature at relatively high temporal (seconds) and spatial (fraction of a km) resolutions from ground and occasionally aircraft platforms. The systems are invaluable in the measurement and studies of mesospheric and lower thermospheric dynamics, composition, chemistry, and thermodynamics. Dynamic studies have been a primary research focus in the understanding of smallscale (gravity) buoyancy waves, tides, as well as planetary waves, and their effects on the middle and upper atmospheric region. The 80-110 km is also an atmospheric region where chemiluminescent emissions from recombination chemistry provides rich remote sensing information on wave dynamics, correlative to that provided by lidar.

Ground based lidar has been used to study the mesopause region (80-105 km) using Na resonance by the U of Illinois (C. Gardner) and Colorado State University (J. She). An example of Na resonance lidar data from ground based measurements made by the University of Illinois resonance system is shown in Fig 1, below [similar to that described by Li et al., 2007]. The Illinois system, currently operating in Chile, is described by Carlson et al. [2005]. The measurements by lidar have made important contributions to the understanding of a number of investigations including the intrinsic properties of small scale waves, tides, and planetary waves, metal densities, momentum, heat, constituent fluxes, and a host of contributions, often with correlative measurements by radars and imagers from this chemically active atmospheric region.
A demonstration of community motivation

Members of the Scientific Community have organized a number of mission plans and proposed to the highly competitive Explorer program to study coupling of

waves into the upper mesosphere and thermosphere from the lower atmosphere using passive remote sensing methods. These investigations from space have not been achieved to date. Among these experiments include the TIPE experiment proposed to AO No. 92-OSSA-1, (Accepted but descoped from the NASA TIMED mission due to $), WAVES Explorers to AO-98-OSS-03 [1998] and AO 01-OSS-03 [2001], as well as Thermospheric Waves Explorer (TWEX), proposed to AO 03-OSS-02 [2003]. The problems associated with wave coupling from the lower to the upper atmosphere remain as important global atmospheric and ionospheric

Figure 1. Time-height contours of (a)temperature, (b)Na density, (c) zonal wind and (d) meridional wind. This was taken at Maui HA, with a 1.5 W Na wind/temperature transmitter.
problems to be solved. Ground based research is ongoing and has made progress, but global perspectives are not understood [e.g. Ground based measurements: Link].

**Mesospheric Resonance LIDAR, and Na, 589 nm.**

LIDAR would enable important technology to make significant enhancements to the global investigations of atmospheric coupling, upward through the mesopause boundary into the thermosphere. The ESA has performed a major study to perform metal lidars (sampling the mesopause region) from space in the past 2 years. Their community is taking this very seriously, with US technologist and technologies contributing to the ideas.

Mesospheric sampling from space would ideally be performed in the FUV where Earth backgrounds and albedo’s protected by the ozone shield, although traditional visible resonance schemes using visible wavelengths can also be engineered to function, just as CALYPSO has.

Technology is rapidly advancing in the area of diode laser technologies and all of the special needs of reliability and space ruggedness for technical readiness. Solid state technologies are rapidly evolving including fiber amplifiers. A very special technology that is very exciting for the metals is the vapor alkali, a new class of lasers suited to Na and K lasers, recently demonstrated by Readle et al. [2009, 2010] for Cs and Rb. For Na, this technology would require a 532 nm pump laser (already in space) and a gas cell. LIDAR transmitters don’t get any simpler in technology or components than this. This US innovation could put this remote sensing capability, with reasonable wall plug to transmitted power. Power efficiency is among the major considerations in orbiting active LIDAR experiments.

**Thermopsheric Resonance LIDAR, and He 1083 nm.**

Emerging technologies are enabling thermospheric LIDAR development, including a He resonance LIDAR capable of sensing in the 250-700 km altitude region [Carlson et al., 2008]. A ground based laser has been built and demonstration on the atmosphere is in process. This will demonstrate thermospheric lidar applications for the first time.

The principles of resonance with the He lidar is the ground state helium is pumped into the 2^3S state by photoelectrons at low and mid latitude, and that state is metastable and very long lived to form a resonant population. Associative recombination of He ions also produce the metastable.

\[
\text{He} \left(1^1S\right) + e^* \rightarrow \text{He} \left(2^3S\right)
\]

\[
\text{He}^+ + e \rightarrow \text{He} \left(2^3S\right)
\]

This population has been simulated initially by Gerard et al., 1997, and later by Waldrop et al., 2006, based on the analysis of Waldrop, 2005 [See Fig 2.].
The He resonance lidar development employs a solid state transmitter. The laser has been built, and stages of amplification are planned to generate 50W. This technology can be further developed into a pulsed laser, with the ability to perform altitude sensing of the thermosphere between 300 and 800 km. 3-frequency tuning of the transmitter enables Doppler receiving, for measurements of altitude profiles of winds and temperature in the thermosphere, at spatial scales to sample waves and structure, not hitherto able to be measured. Sampling vertical resolutions on the order of km, at time scales of 10’s of seconds, can be accomplished with a relatively low power system (few watts, average power). He metastable populations described in Fig 2 have been used to describe S/N of > 20 from ground based lidar [Carlson, 2008].

![Figure 2: Metastable He(2^3S) density [m^{-3}] as a function of altitude for midlatitude, Northern hemisphere, solar maximum conditions with a solar zenith angle of 90°. From [Waldrop, 2006]](image)

Figure 3. A solid state laser has been developed to generate 10 W of CW, at 1083 nm for ground based lidar testing using bistatic imaging of thermospheric resonance.
Summary

Key lidar technologies in resonance lidar with metals and He are enabling a new dimension of upper atmospheric remote sensing, not unlike the lower atmosphere community is experiencing from CALYPSO. Lidar designed to study upper atmospheric enables a new dimension of spatial and temporal sampling of density, temperature, and wind. It is timely to develop simulations and carefully evolve the hardware which is practical to employ in space to investigate our upper atmosphere.

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References
CALIPSO LINK: http://www-calipso.larc.nasa.gov/
CEDAR: Lidar beyond Phase III, Accomplishments, Requirements, and Goals, with 241 publications, March, 2004
http://cedarweb.hao.ucar.edu/wiki/index.php/Community:Documents

Figure 4. An image of serial number 1, of a He 1083 resonance laser on a tabletop breadboard assembly at the U of Illinois, Remote Sensing and Space Science group.

Ground Based Instruments LINK:  
http://cedarweb.hao.ucar.edu/wiki/index.php/Documents:Ground_Based_Instruments


LITE: http://www.nasa.gov/centers/langley/news/factsheets/LITE.html


