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Midlatitude, Rayleigh-Mie-Raman Lidar for Observations from 15 to 120 km

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www.usurayleighlidar.com

IAGA2013, Merida, Mexico  
27 August 2013
Original ALO Rayleigh Lidar

• Description
  o Build by Vincent Wickwar, John Meriwether, and Tom Wilkerson
  o \( \sim 21 \text{ W} \) (700 mW at 30 Hz) at 532 nm & 0.44 m mirror —
    \( \text{PAP} = \sim 3.1 \text{ Wm}^2 \)
  o Good data from 45 to \( \sim 90 \) km for 1993 – 2004

• Science
  o Temperature Climatology
  o Noctilucent Clouds
  o Thin Aerosol Layer
  o Mesospheric Inversion Layers
  o Brunt-Väisälä Frequency Climatology
  o Characterization of Mesospheric Gravity Waves
  o Upward Propagation of Gravity Waves — Growth and Energy Loss
  o Secular Trends in Temperatures from 11 years of data
  o Solar Cycle Effects on Temperatures
  o Sudden Stratosphere Warmings
  o Cold Island in October near 80-87 km
  o Extremely Cold Januaries

Sox et al., IAGA2013 2.5-14
Fish et al., IAGA2013 2.5-16
Science Examples (1/2)

Density Climatology — CPC Reference

Temperature Climatology

See Barton et al., IAGA2013 2.5-23p

[Adapted from Herron, 2007; Barton et al., 2013]
Convective Instability on Topside of a Mesospheric Inversion Layer

Noctilucent Cloud at Midlatitude, at 41.7° N

19 February 1995 — All-night Int.

MSISe00

Temperature [K]

dT/dz [K/km]

N²x10⁻¹ [rad/s]²

Brunt-Väisälä Period

[Adapted from Durga, 2009; Herron et al., 2007]
Upgrade Overview — 207 Wm²

• Greater sensitivity to open the 90 – 120 km region for neutral density and temperature observations from the ground.

• Greater precision and accuracy below 90 km.

• Extend the observations down to nearly the tropopause. Add a Raman scatter capability from N₂ at 607 nm to account for Mie scatter and extinction from aerosols.

• Can follow structures, disturbances, and waves as they emerge from the troposphere and propagate, on occasion, all the way into the thermosphere, or dissipate, or reflect.

• Obtain absolute density calibration at the lowest altitudes. This gives absolute densities between 90 and 120 km where all the thermospheric neutral models begin.
Block Diagram of Rayleigh Lidar

Telescope:
Four, Coaligned,
1.25 m mirrors.
Prime focus.
4.90 m².

PMTs
- Raman
- High Rayleigh
- Mid Rayleigh
- Low Rayleigh

Cold H₂O
LV PSUs
HV PSUs

Optics
- Choppers
- Interference Filters

Microprocessor
Controlled Timing

18 W Nd:YAG Laser
24 W Nd:YAG Laser

Four Multi-
Channel Scalers

4 Fibers

4x Beam Expanders

Computer

Three Servo Controllers
ALO Observatory
Rayleigh Lidar Telescope

Cage: 3-m Square x 2.5-m High Laser Beam Through the Middle

Fiber Assembly (Not yet Finished)
ALO—Rayleigh and Na Lidars in Operation

[Photo by Thomas Amely, 2012]
18-Day Solstice Campaign — June/July ‘12
Discussion of Temperature Structure

• Huge day-to-day variability — greatly exceeding uncertainties
• Temperatures often low enough for noctilucent clouds — however, no NLCs
• Because of this variability, the “mesopause” has to be a statistical concept

① New & Original Rayleigh temperatures agree between 75 & 79 km.
   Proof that data acquisition and analysis of New Rayleigh are working properly.

② New & Original Rayleigh ~18 K cooler than MSISe00.
   Suggests a systematic offset in MSISe00 at mid latitude near solstice.

③ New Rayleigh still ~12 K cooler than MSISe00 at 87 km.
   The possible systematic offset in MSISe00 continues upward.

④ New Rayleigh and MSISe00 agree from 92 to 99 km.
   Artifact because MSISe00 provides the initial temperatures for the New Rayleigh data reduction. (Effects 10 to 15 km for a temperature error of 15 K.)

⑤ Old Rayleigh greater than MSISe00 and New Rayleigh by 10 and 20 K at 90 km.
   Artifact because initial temperatures for the Original Rayleigh came from CSU Na lidar climatology. But, it suggests that that Na climatology was too warm.

• The last two items indicate the importance of
  – New Lidar data going all the way to 120 km or higher
  – The new analysis technique advanced by Khanna et al. [2012] of UWO
System — What Next?

- Last summer reached 109 km (all-night integration).
- So far this summer reached 114 km (2 hours). Would mean 120 km for an all-night integration.

- Optimize the subsystems. (The new goal is 130 km.)
- Implement Khanna et al. [2012] forward method to obtain good Rayleigh temperatures as high as possible. (Eliminate problem in Notes 4 and 5.)
- Finish adding two more Rayleigh detector channels for to go down to ~15 km.
- Add a Raman detector channel for \( \text{N}_2 \) at 607 nm for the lowest altitudes.
- Implement Klett algorithm for the lowest altitude temperatures.
- Add “shoes” to mirrors to prevent them from moving when cage is tilted.
- Move and scan telescope in azimuth and zenith angle to observe structures and waves.
Science — What Next?

• Special campaigns to verify good temperatures at highest and lowest altitudes, and to establish and verify good absolute densities.
• Campaigns (Structure of the region above 90 km, Conditions conducive to NLCs, Seasonal mesopause transitions, Cold island, Sudden Stratospheric Warmings).
• Regular Observations (Climatologies, Coupling between regions, Waves, Disturbances, Special events, Climate change, Solar cycle changes).
• Campaigns with other mesospheric instruments at Logan & Bear Lake Observatory (BLO).
  o Na lidar (Temperatures, winds, sporadic thin Na layers, Na mixing ratio).
  o Airglow imaging of OH, O(1S), and O₂ Atmospheric (Temperatures, waves, and structures).
  o Meteor wind radar (Sudden Stratospheric Warmings).
  o Ionosonde observations (Sporadic E and SIDs).
• Compare with lidar, airglow, and radar observations from other geographical locations, and compare / combine with satellite observations.
• Compare with model calculations.
Summary & Conclusions

• Pushed the state-of-the art to obtain high altitude data with the Big Rayleigh Lidar
  o Used two lasers to maximize the power, ~42 W
  o Used four big coaligned mirrors to obtain a huge collecting area, 4.90 m²
  o Combined the light from four fibers into one beam for detection

• Results on MLT temperature structure from last year’s Solstice campaign
  o MSISe00 appears to over estimate the temperature by 10 – 20 K
  o CSU’s Na temperatures at 90 km are greater than ALO’s Rayleigh temperatures

• Next major upgrade steps
  o Implement the Khanna et al. [2012] temperature reduction procedure
  o Finish three lower altitude channels
  o Implement Klett stratospheric temperature reduction procedure
  o Move and scan the telescope in azimuth & zenith angle

• Next major science steps
  o Campaigns to verify lidar data analysis and to examine special situations
  o Coordinated campaigns with middle atmosphere cluster at Logan & BLO
  o Regular Observations
  o Compare with middle atmosphere measurements from elsewhere and with model calculations
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