# Initial Results from an Automated High Spectral Resolution Lidar

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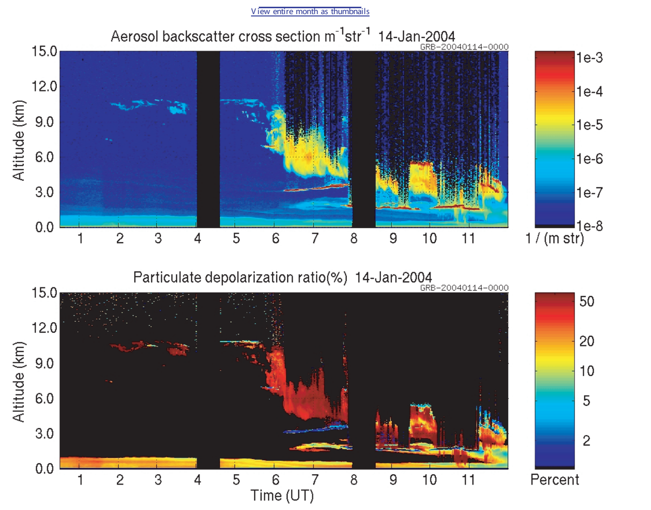
The National Science Foundation has funded construction of a High Spectral Resolution Lidar (HSRL) for long-term unattended operation in the Arctic. This lidar provides robustly calibrated measurements of optical depth, backscatter, cross section and depolarization. It is designed to operate as an Internet appliance with minimal attention from on site personnel. Because Arctic cloud bases are frequently found at low altitudes, special effort has been placed on the near range response of the lidar--observations begin at z=75 m and extend to an altitude of 30 km with a 15 m vertical resolution. Measurements are computed from ratios of the particulate scattering to the measured molecular scattering. This provides absolute calibration and makes the calibration insensitive to dirt or precipitation on the output window. A very narrow angular field-of-view (.045 mrad) reduces multiple scattering contributions. The small field-of-view coupled with a narrow 8 GHz optical bandwidth nearly eliminate noise due scattered sunlight. The lidar is completely eyesafe. One can look directly into the output beam at the exit pupil without danger.

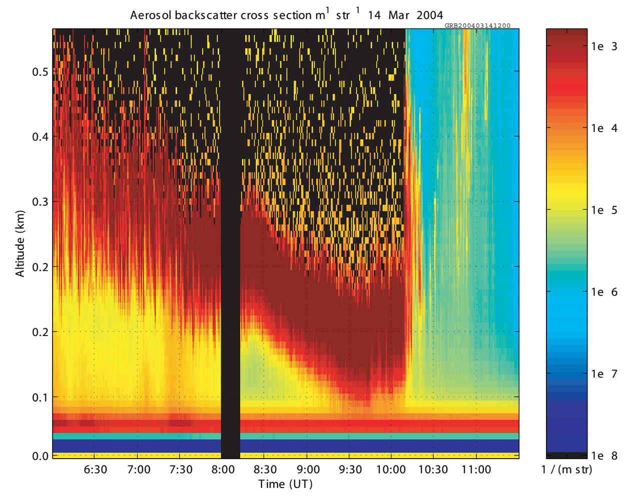
The new HSRL is currently installed under a zenith-facing window on the top of our laboratory. The system operates 24-hours/day and more than 6000 hours of data has been collected during testing. Data is automatically transfered in real time from the lidar to our archive computer via a fault-tolerant client-server application where it is stored as netcdf files on a 1-terabyte raid disk system. All data can be accessed through a publicly accessible web site: 'lidar.ssec.wisc.edu'. Real time access is provided by a web tool which computes images and profiles on demand. The time and altitude interval for the data can be specified. Data may also be searched via web pages which provide a complete month of 12-hour thumbnail images of the backscatter cross section between the surface and 15 km. Clicking on an image provides a full screen version of the backscatter cross section and the depolarization image. An online system log provides information about system maintenance and software modifications. A web tool is provided to display system housekeeping data as well. We are also preparing web routines to process data on demand and deliver the output to users in netcdf format.

## Arctic HSRL Web Site Quick-Look Data Selector
http://lidar.ssec.wisc.edu

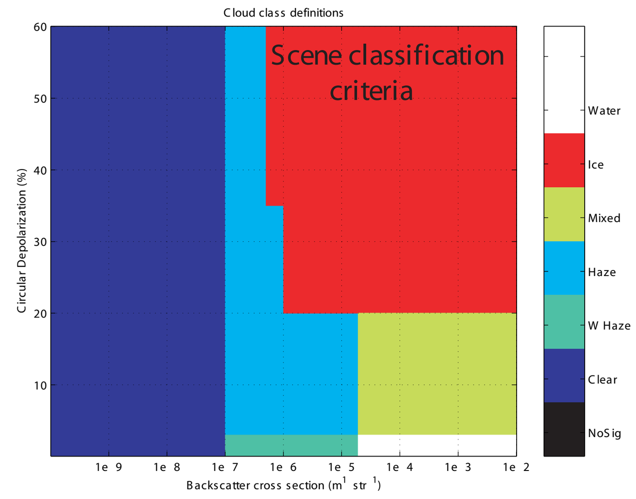

Backscatter cross section thumbnails provide a month-long visual index to HSRL data. Clicking on a thumbnail (Jan 14 in this case) provides full-screen backscatter and depolarization images.




## Cloud base measured at z=100 m on 14-Mar-04



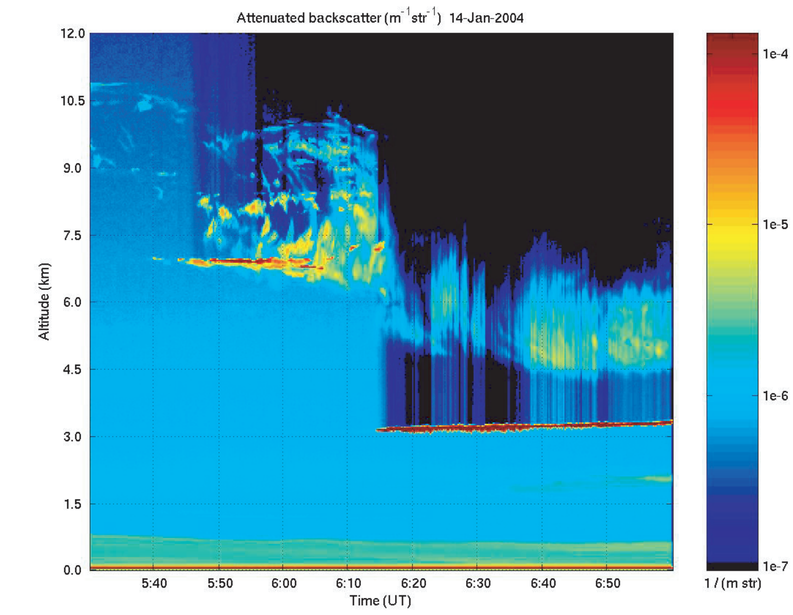
Most lidars have a near-range overlap region where observations are not possible. The HSRL recovers from saturation at ~ 75 m, allowing low altitude measurements. Backscatter cross section measurements are insensitive to overlap effects because they are computed from the ratio of particulate to molecular signals. This also makes the measurements insensitive to precipitation or dirt on the external window.




This provisional classification scheme does a reasonable job of segregating a scene according to the type of atmospheric scattering even though the exact location of boundaries are subject to question. The mixed classification includes some ice clouds which exhibit low depolarization--probably indicating that a large fraction of the backscattered signal is due to specular reflection from crystal faces.

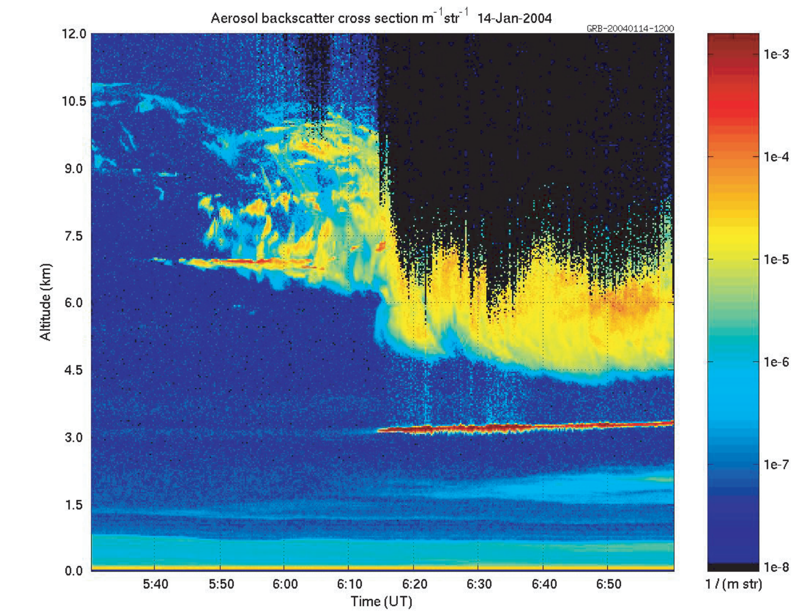
A Real-Time Quick Look Image tool provides custom images and line-plots of data products for user specified times and altitudes data is processed on demand from the archive.

## Standard Lidar image showing effects of attenuation



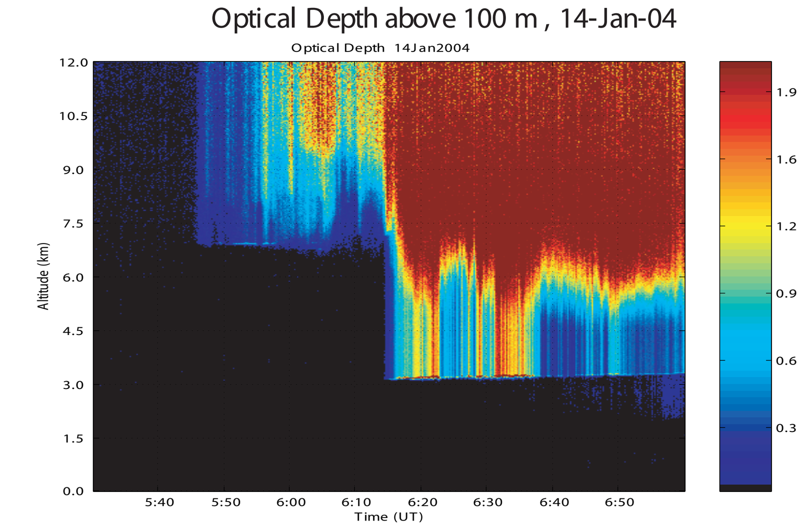

Upper layer cloud structure is shadowed by lower clouds in the standard lidar image. Any attempt to correct for attenuation requires questionable assumptions about the scattering properties of the obscuring clouds. Fine details of aerosol layers are masked by strong molecular scattering.

## HSRL image of calibrated backscatter cross section

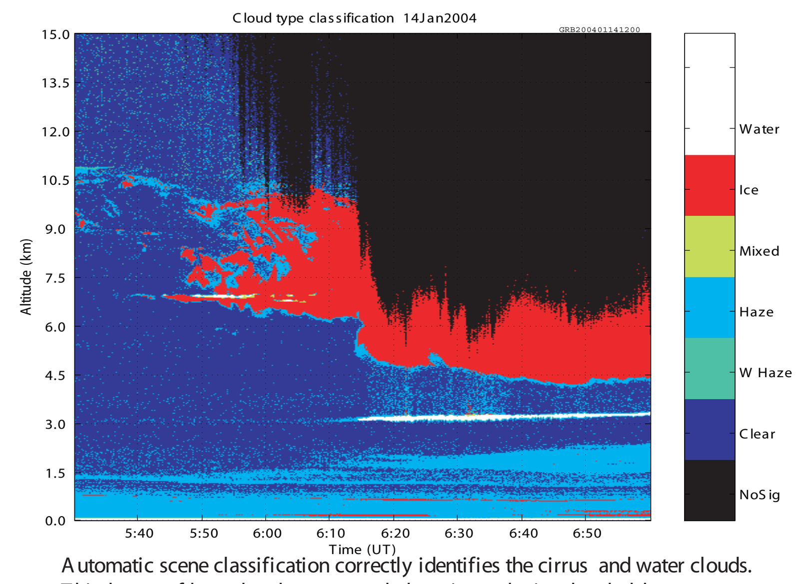



The HSRL image of backscatter cross section rigorously corrected for attenuation; shadows artifacts are removed. Obscured areas are objectively determined from the stength of the molecular signal. Also notice the enhancement of tenuous aerosol layers after removal of the molecular scattering.

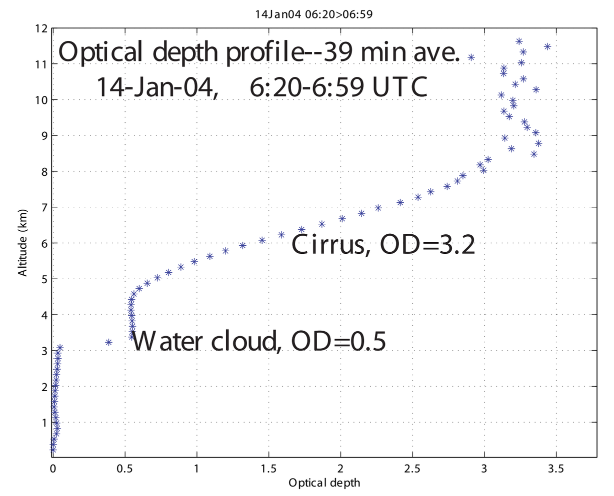
## Optical Depth above 100 m , 14-Jan-04



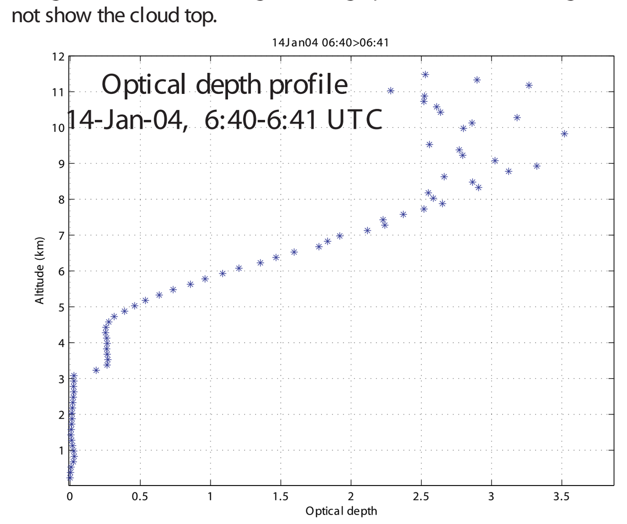

This plot shows the optical depth as a function of altitude measured from a reference point a z=100 m.



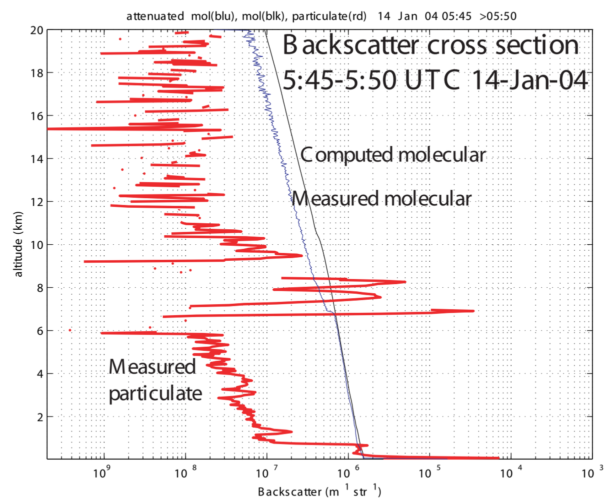

Automatic scene classification correctly identifies the cirrus and water clouds. Thin layers of boundary layer aerosol also trigger the ice threshold.



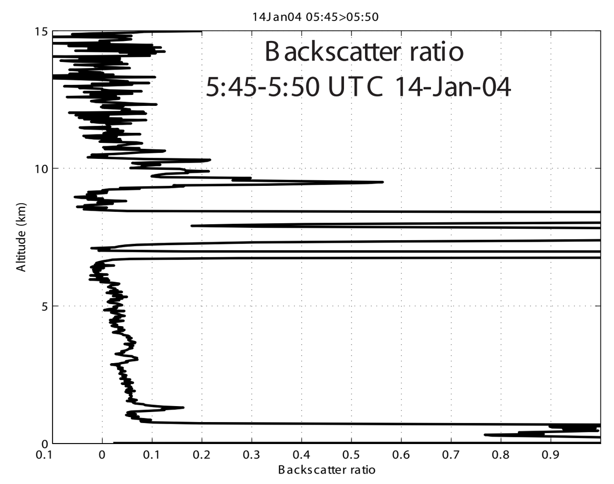

A 39-min average profile extends through the entire cirrus cloud even though the 12-second averages making up the backscatter image does not show the cloud top.



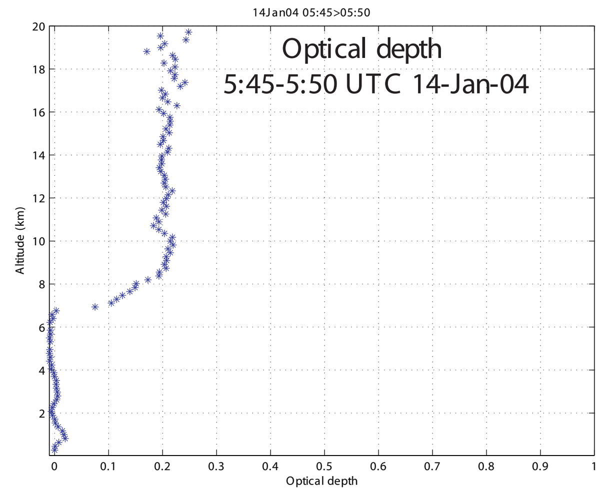

The HSRL can measure optical depths up to approx. OD=3 using a one-minute average, for longer averages OD greater than 4 are observed.




This 5-min average provides profiles to an altitude of 20 km. Notice the effect of cirrus attenuation at 6 km on the measured molecular profile.

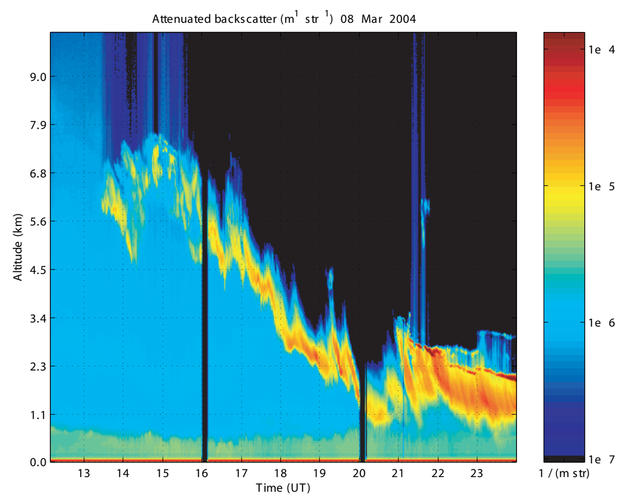



The calibration accuracy of the HSRL is illustrated in this expanded view of the backscatter ratio. Minimum values, reflecting aerosol free layers, show backscatter ratios of zero.



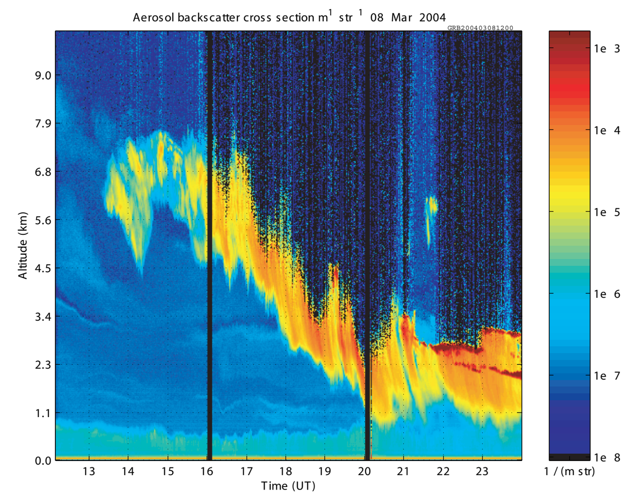

This 5-minute average provides stable optical depth measurements up to an altitude of 20 km. Errors in the near range geometry correction produce the ~0.03 OD fluctuations seen below 4 km while statistical noise is responsible for the the fluctuations seen above 10 km.

## Standard Lidar Image, 8-Mar-04



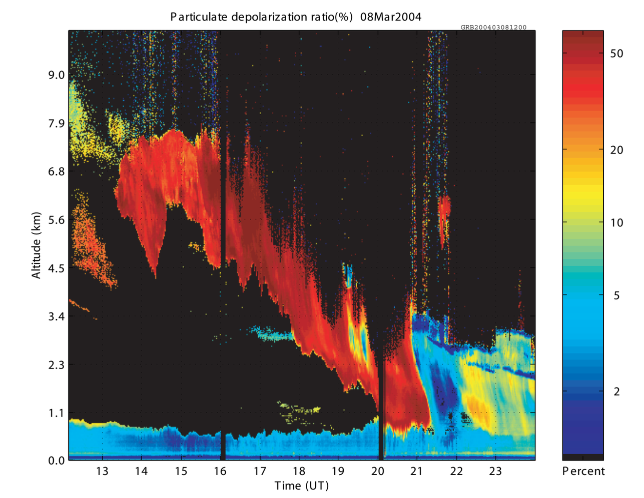

This standard lidar image was created using a single channel of the HSRL. Only the lower edge of the cloud is visible due to attenuation. The boundary layer aerosol layer is evident but elevated aerosol is mostly masked by molecular scattering.

## Attenuation corrected backscatter cross section



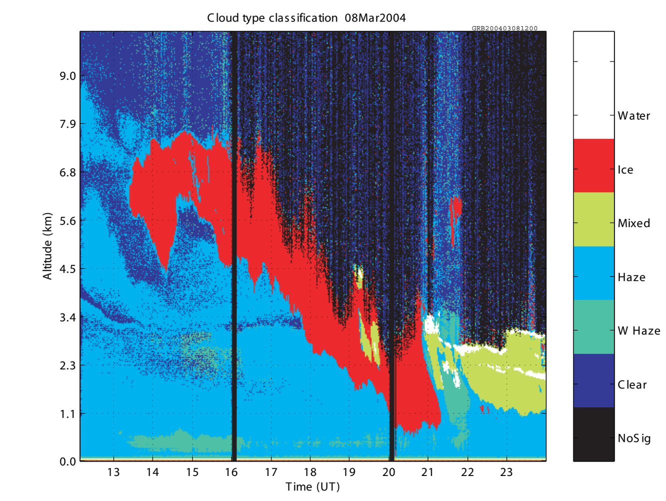

Note increased contrast in aerosol layers due to lack of molecular scattering in the particulate backscatter cross section image. Image features are either visible, with the correct backscatter cross section assigned, or depicted as black, indicating that insufficient signal was detected for the HSRL data inversion.

## Circular depolarization image, 8-Mar-04

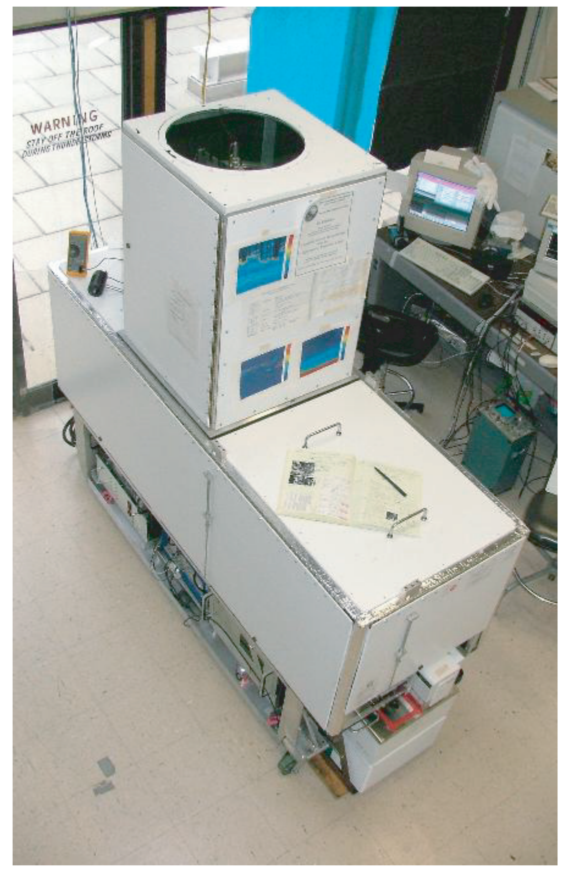



Depolarization distinguishes between spherical and non-spherical particles. Notice the abrupt change in precipitation type at 21 UTC.

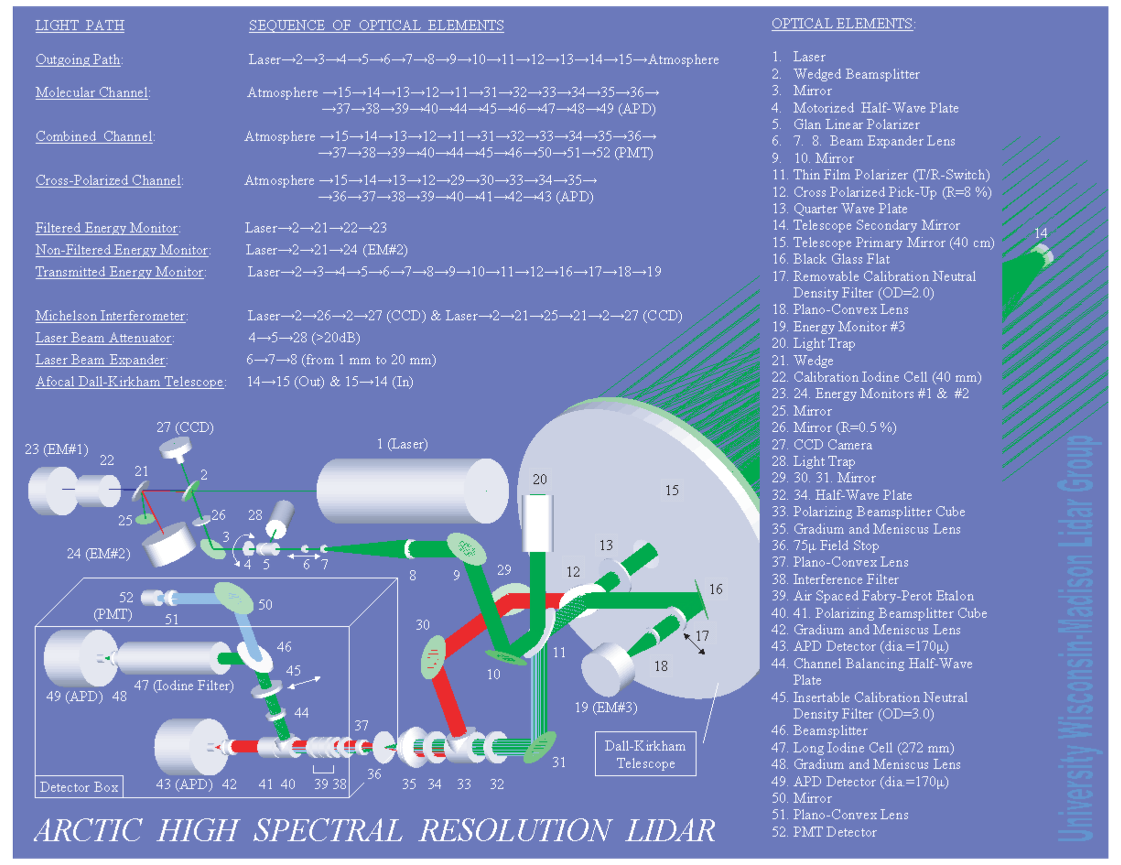
## Automatic Scene Classification, 8-Mar-04




Automatic scene classification is possible using calibrated measurements of the circular depolarization and backscatter cross section. These images are generated on demand by web based software and are useful in initial data screening.



The University of Wisconsin Arctic HSRL




Schematic showing optical layout of the HSRL

UW Arctic HSRL Specfiications

| | |
|---|---|
| Average transmitter power | 600 mw |
| Pulse repetition rate | 4 kHz |
| Wavelength | 532 nm |
| Solar noise bandwidth | 8 GHz |
| Angular field-of-view | .045 mrad |
| Telescope diameter | 40 cm |
| Optical detectors | Geiger-mode APD's, PMT |
| APD quantum efficiency | ~60% |
| PMT quantum efficiency | ~5% |
| Data acquisition | Photon counting |
| Range resolution | 7.5 m |
| Max time resolution | 0.5 sec |
| Max optical depth | 4.5 |

Key Design Features

- Remote Operation: Designed for continuous remote untended operation as an Internet appliance.
- Transceiver Design: Laser light goes through same optics for maximum stability of transmit and receive optical axis.
- Passive TR switch: Polarization is used to separate the transmitted laser pulse from the atmospheric returns.
- Near Range Measurements: Calibrated measurements begin at z=75 m.
- Narrow field-of-view: Nearly eliminates solar background noise and multiple scattering errors.
- Stable Narrow Band Filter: Fixed-gap Fabry-Perot etalon is pressure tuned by computer with bellows chamber.
- Stable Iodine Notch Filter: Precise temperature control provides stable spectral characteristics (line width and rejection).
- High Efficiency Detector: A Geiger mode avalanche photodiode (APD) provides high quantum efficiency in molecular channel.
- Eye Safety: The laser bream is spread over sufficient area to allow safe viewing of the output beam.
- Low Maintenence Projected lifetime of laser pump-diode module is 9000 hours (first failure experienced after more than 6000 hours)