Lidar observations at IRF

Background

IRF hosts several instruments for observations of different physical and chemical characteristics of the atmosphere. There are two main aspects which make our location interesting for atmospheric research. One is that Kiruna during winter lies sometimes inside, sometimes outside the polar vortex, an stratospheric air mass roughly centered around the North Pole with very peculiar chemical characteristics due to limited exchange across the vortex boundary. Additionally, air inside the vortex is relatively cold. If temperatures are sufficiently low, appr. below 196K, so-called Polar Stratospheric Clouds (PSCs) can form which enhance ozone depletion. Secondly, Kiruna is a location where internal gravity waves frequently can be observed. Such waves can develop when air flows across mountains. Air parcels which are forced upward on the windward side will descent behind the mountain to reach the state of equilibrium. Overshooting that state results in vertical oscillations further downstream, so-called internal gravity waves. Depending on horizontal wind and atmospheric stability waves can propagate all the way up to the mesosphere, effectively transporting energy to higher altitudes. A result of the oscillation is that air parcels cool down and warm up as they move upward or downward, respectively. Over Northern Scandinavia a visible consequence during winter are lenticular PSCs. Very often it requires additional cooling from those oscillations to form PSCs since synoptic temperatures usually are too high. Studying signatures of gravity waves in PSCs is currently the main purpose of our lidar observations.

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He then was a research fellow at City University, Hong Kong, SAR China, before he joined the Swedish Institute of Space Physics (IRF) in Kiruna, Sweden in 2002. Since then he has been responsible for lidar research at IRF.
Research interests: troposphere, stratosphere, single-particle scattering, and, of course, lidar remote sensing.

System setup

The lidar at IRF utilizes as transmitter a Nd:YAG laser. Wavelength is 532nm, i.e. the laser light is green. The pulse repetition rate is 30 Hz. Before being emitted into the atmosphere the light pulses pass through a couple of optical devices to enhance the beam quality:

- A beam lock unit improves the pointing stability of the laser, hence, reducing jittering of the laser beam.
- A Brewster window ensures that the laser light is perfectly linearly polarized.
- A beam expanding telescope. This increases the diameter of the laser spot right after the telescope (in our case by a factor of 5), but at the same time reduces the divergence of the laser beam by the same factor. The reduction is beneficial in distances of several kilometres and beyond as then the effect of the reduced divergence outweighs the larger initial spot size. (An example: A typical laser has a beam divergence of 0.0005 radian or 0.03 degree. This means that in 10 km distance the laser spot has a diameter of 5 m. In our case the spot size is only 1 m.)

Thereafter laser pulses are emitted into the atmosphere via a mirror with precision motors to control its orientation. The purpose of the motors is to correct alignment when required (e.g. misalignment due to thermal effects).

The backscattered light from the atmosphere is collected by telescope of Cassegrain type. The diameter of the primary mirror is 0.45 m, focal length is 2.7 m. The light is split according to its state of polarization (linear and perpendicular) and then focused on detectors. A couple of tools are applied to improve signal quality:

- A pinhole behind the telescope reduces the field-of-view (FOV) and, accordingly, the amount of unwanted straylight. The goal is to have the FOV just large enough to have the complete laser spot in the FOV for the altitude range to be investigated. In our case, a pinhole with 1mm diameter is used.
- Optical filters transmit only a small wavelength range around the laser wavelength and in this way reduce the amount of background radiation on the detectors.
- A mechanical chopper closes the detectors for a certain period after a laser pulse is transmitted. This protects the detectors from exposure to very high signals from the near range (which could lead to saturation).

The detectors are Hamamatsu-built photomultipliers which have been modified by Licel GmbH for lidar applications. The data acquisition system behind the detectors allows for that signals are simulataneously recorded in analog and photon-counting mode. A consequence is that the possible signal range of the detectors is significantly increased.

Data is stored as averages over 4000 shots, roughly 130 s. Our vertical resolution is usually 30m.

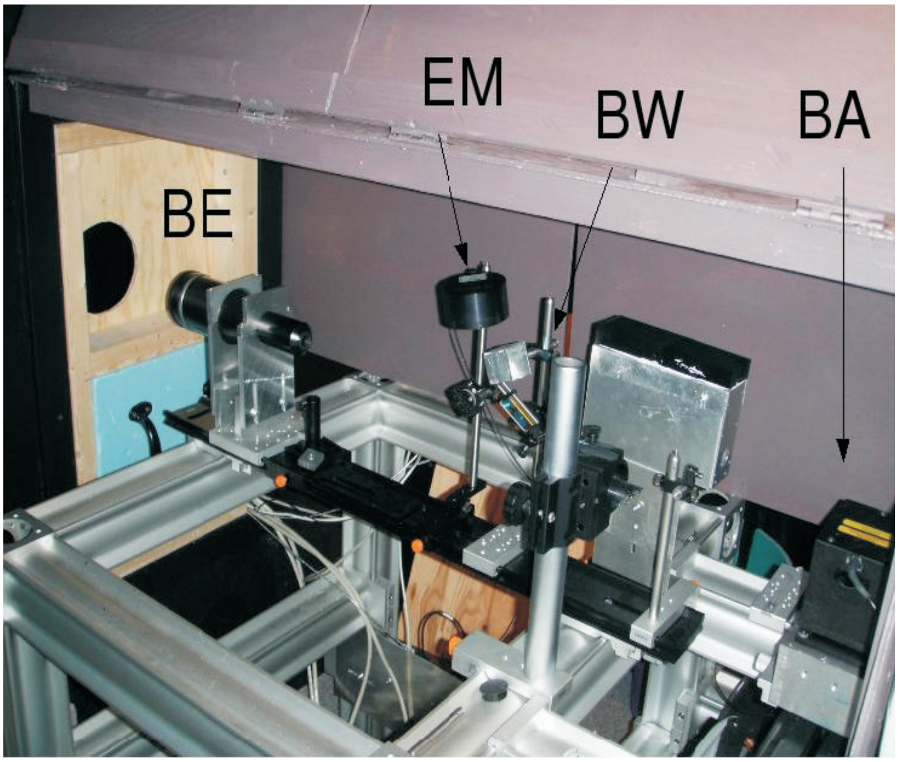


Fig. 1: Optical elements of the transmitter. BA: Beam alignment unit; BW: Brewster window; EM: Energy monitor; BE: Beam expanding telescope. The laser is on the right side, just outside the picture.

Observations

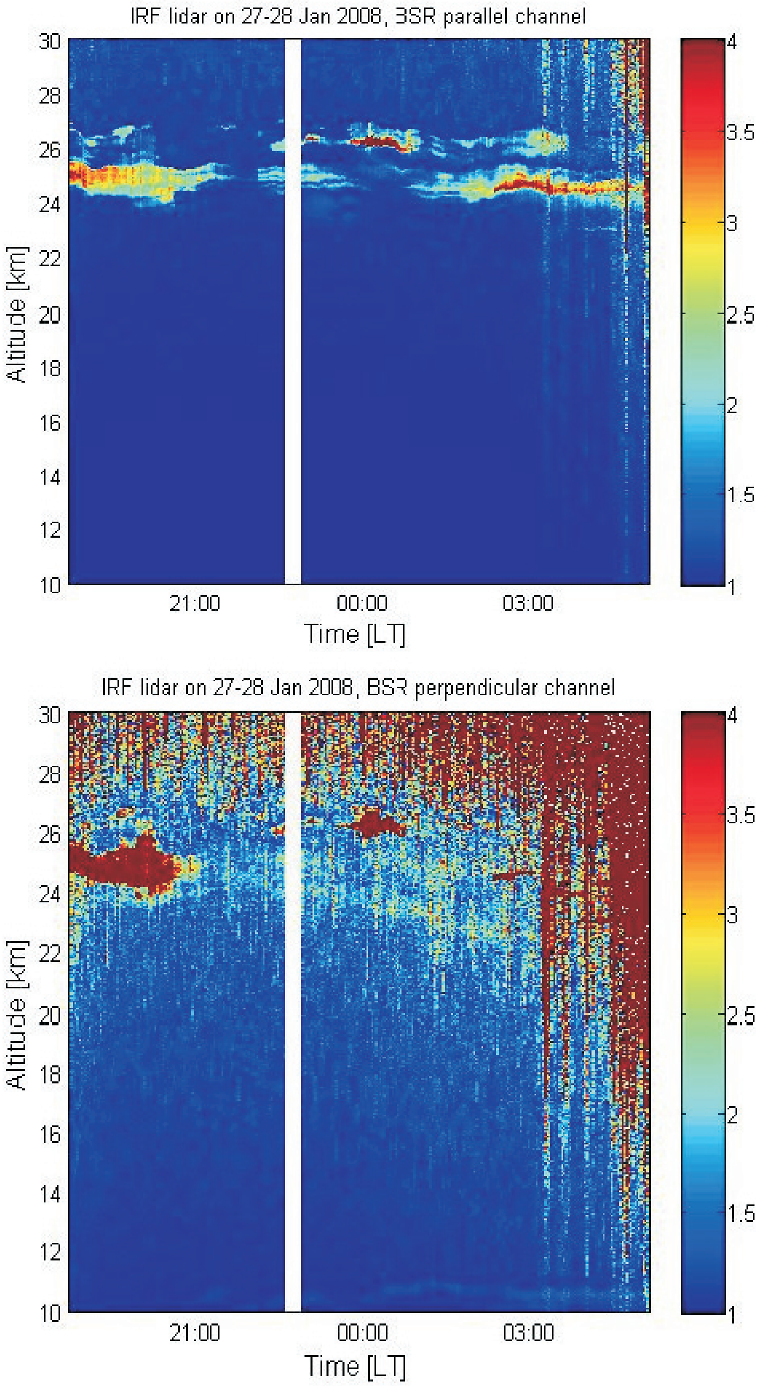
The intensity of the backscatter signal gives information about the density of scatterers as function of height. Polarization reveals something about their characteristics. Spherical particles (i.e. droplets) do not change polarization of light in the case of scattering in backward direction. On the other hand, nonspherical particles (e.g. crystals) do changepolarization. The combination of both signal intensity and polarization gives a classification of different PSC types according to the chemical composition. The cloud formation temperature depends on cloud composition, hence, the

Wavelength:	532nm
Energy per pulse:	0.55J
Beam divergence (after beam expander):	0^{-4}rad
Diameter primary mirror of telescope:	0.45m
Bandwidth of filters:	10nm
Detectors:	Hamamatsu R7400P, Analog and photon counting
Height range:	5 – 50 km
Height resolution:	typically 30m
Time resolution:	ca. 130 s

Table 1: System characteristics of current IRF lidar

classification allows for rough estimates of the temperature in a cloud.

Fig. 2 presents one example of measurements from the night 27/28 january, 2008. Shown is the backscatter ratio (BSR), the ratio of total scattering to molecular scattering. High numbers are equal to thick clouds. During the night several distinct patches of PSCs were detected. The signal in the parallel channel shows that the clouds had ripple-like structures, indicating that waves were present. From the perpendicular channel it can be seen that some of the clouds depolarized the signal strongly, an indication that the PSCs consisted of ice. The formation temperature for ice PSCs is lower than for other types of PSCs and was during that night never reached synoptically. Only cooling in gravity waves could have resulted in these PSCs.


IRF lidar on 27-28 Jan 2008, BSR parallel channel

IRF lidar on 27-28 Jan 2008, BSR perpendicular channel

Fig 2: Lidar observations from night 27/28 january, 2008.

Upgrade

Gravity waves are not only of importance for the vertical energy transport but can also result in breaks in the tropopause. Only such breaks allow for exchange of larger volumes of air between troposphere and stratosphere. Stratospheric air has higher concentrations of ozone. Hence, events with large entrainment of stratospheric air can increase levels of tropospheric ozone. Therefore, ozone concentration can be used as a tracer to investigate occurance and severeness of such events. Ozone can be measured by lidar with the so-called DIAL technique (Differential Absorption Lidar), where pulses at two wavelengths are transmitted. The wavelengths must be chosen from a range where ozone absorption changes with wavelength. Then, the differences in the backscattered signals are a measure of the ozone concentration. The best-suited wavelength region for lidar measurements of ozone is the Hartley-Huggins band between 250 and 310 nm (i.e. in the uv). Our laser can create light at 266nm. This is simply done by adding a crystal into the beam which is able to convert light at 532nm to 266nm. The harder task is to create a second wavelength in the uv. For this purpose a so-called Raman cell can be utilized, basically a tube filled with certain gas mixture under high pressure. When a laser beam is directed into the tube the gas converts part of the laser energy to light with a different wavelength (stimulated Raman scattering). The wavelength shift depends on the gas, but is typically between 10 and 20nm. The optimal conversion rate depends mostly on laser energy and gas pressure but also on several other factors. The optimum settings for our setup are currently under investigation.