Noctilucent clouds: research at the edge of space

Gerd Baumgarten and Franz-Josef Lübken

Studying the highest cloud layer in the upper atmosphere presents a significant technical challenge for remote-sensing techniques.

The first observational reports describing noctilucent clouds (NLCs, luminous clouds visible after sunset: see Figure 1) were published some 120 years ago. It was quickly realized that NLCs are located at significantly higher altitudes than typical clouds. Following lengthy speculation, it was recently proven that they consist primarily of water ice. Already in 1887 it was proposed to use light for active remote sensing of the NLCs, although it took until 1989 for the light-detection and ranging (lidar) technique to develop the required sensitivity.

Since 1994, the Rayleigh–Mie–Raman (RMR) lidar (see Figure 2) at the Arctic Lidar Observatory of Middle Atmosphere Research (ALOMAR) in northern Norway (latitude 69° N) has been operated routinely for the observation of the middle atmosphere, at altitudes of 10–100 km. The key challenge in using a lidar for NLC studies is their extremely small optical depth, of only $10^{-6}$ to $10^{-4}$. Since NLCs are found at high latitudes in summer, where the midnight sun impedes lidar observations, a special instrument setup is needed, also allowing for daytime lidar operation.

The ALOMAR RMR lidar allows cloud observations in two independent directions using two telescopes with primary mirrors of 1.8 m diameter. Two lasers of 160 MW peak power are used to simultaneously emit light at three wavelengths (355, 532, and 1064 nm). Each laser beam has a diameter of 20 cm and is emitted along the telescope’s optical axis to minimize the required field of view (see Figure 3). Active control loops are used to keep the laser beam inside the field of view, with an accuracy of 1 m at a distance of 100 km. The light collected by the telescopes is guided to a multiwavelength detection system that uses narrow-band etalons (with ~4 pm line separation) to suppress sunlight scattered by the atmosphere and subsequently collected by the telescopes. Fast avalanche photodiodes with a quantum efficiency of about 50%, combined with photomultipliers, are used to record single backscattered-light photons.

Using the most sensitive receiver channel, the lidar observes NLC development with a time resolution of about 1 min, even if the sun is above the horizon. The lidar observes small-scale variations clearly, some of which show a wave structure, e.g., at 6 h UT (universal time) on 25 June 2007 (see Figure 4). The downward progression of the cloud layer during the morning hours is a phenomenon that reoccurs regularly. It is caused by tides in the upper atmosphere.

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Figure 3. Laser-beam guiding in the ALOMAR telescope hall. The beams are guided along the optical axis of the two 1.8m-diameter telescopes.

Figure 4. NLC time sequence observed with the ALOMAR RMR lidar 24 and 25 June 2007. The clouds show a pronounced downward progression and short-period (∼10min) wave structures.

Using backscattering measurements at three widely-separated wavelengths, we retrieve the size of the cloud particles by modeling the ‘color ratios’ (i.e., the ratios of the backscattering coefficients at two different wavelengths). Since the ice particles are small and nonspherical we use a state-of-the-art t-matrix code. Particle-size retrieval is achieved with a time resolution of 15min. In the period from 1998 to 2005 we found a mean (volume-equivalent) particle radius of 47.7±1nm on the basis of 142h of measurements. On average, we only observed about 85 particles cm−3.

The lidar measures the cloud’s volume density, which is needed to estimate the importance of the NLC’s freeze-drying effect. During particle growth they accumulate the surrounding water and descend to lower altitudes since the thin atmosphere at high altitudes cannot lift particles of even only a few ×10nm across. During their lifetime, the particles are transported away from the pole because of global circulation patterns, and eventually the water is released when the cloud evaporates at lower altitudes and latitudes. We find that between 200 and 500tons of ice particles are present in the latitude range from 65 to 75°N.

Although many open questions remain, which require even more detailed observations and the combination of multiple remote-sensing methods, many NLC properties are already reasonably well understood. For example, the presence of NLCs can be used as a tracer of temperature and water vapor at the relevant altitude (∼83km). We have found that the cloud peak altitude closely follows the 145K isothermal in the atmosphere. This means that NLCs are found at the lower boundary of the summer-mesopause region (at altitudes of 83–90km), the coldest region in the earth’s atmosphere. Hence, the clouds act as a thermometer that visualizes the summer paradox of the upper atmosphere, i.e., although the sun shines 24h a day in summer, temperatures are much lower than in wintertime. The clouds can easily be seen, e.g., on transcontinental flights looking toward the north (see Figure 5). One might see NLCs shortly after sunset or just before sunrise. If one follows the wave structure and its dissipation with time, one will get an impression of the importance of small-scale fluctuations for the mean state of the polar upper atmosphere. Future observations using fast and precise lidar measurements will greatly improve our knowledge of these fluctuations. This in turn will help us to understand the upper atmosphere and global-circulation patterns.

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The ALOMAR RMR lidar is a joint project of the Centre National de la Recherche Scientifique in France and the Leibniz Institute of Atmospheric Physics (IAP) in Germany. The IAP is responsible for instrument performance, improvements, and operation.

Author Information

Gerd Baumgarten
Department of Optical Soundings
Leibniz Institute of Atmospheric Physics
Kühlungsborn, Germany
http://www.iap-kborn.de/index.php?id=84&L=1&user_detail=76
http://www.iap-kborn.de

Gerd Baumgarten is a physicist. His main research interests include lidar remote sensing of aerosols, temperature, and wind in the middle atmosphere using the ALOMAR RMR lidar in northern Norway. He also studies optical signatures of NLC particles and particle microphysics in global NLC models.

Franz-Josef Lübken
Director
Leibniz Institute of Atmospheric Physics
Kühlungsborn, Germany
http://www.iap-kborn.de/Staff.84.0.html?&L=1&user_detail=103
http://www.iap-kborn.de

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