Atmospheric Research at Top of Germany: Zugspitze Mountain 2.962m

Modified UV Laser System Enables Remote Raman Sensing

Scientists measuring atmospheric water vapor by Raman backscatter needed a high power ultraviolet laser with narrowline output to extend the range of measurements to higher altitude. Located in an observation station on Mount Zugspitze in Germany, researchers modified a 350 watt industrial XeCl excimer laser from Coherent and combined it with larger signal collection optics to increase system S/N by a factor of about 40X compared to typical 355 nm Nd:YAG based Raman-lidar instruments. They can now quantitatively measure water vapor to altitudes as high as 22 km with a 10X reduction in data acquisition times.

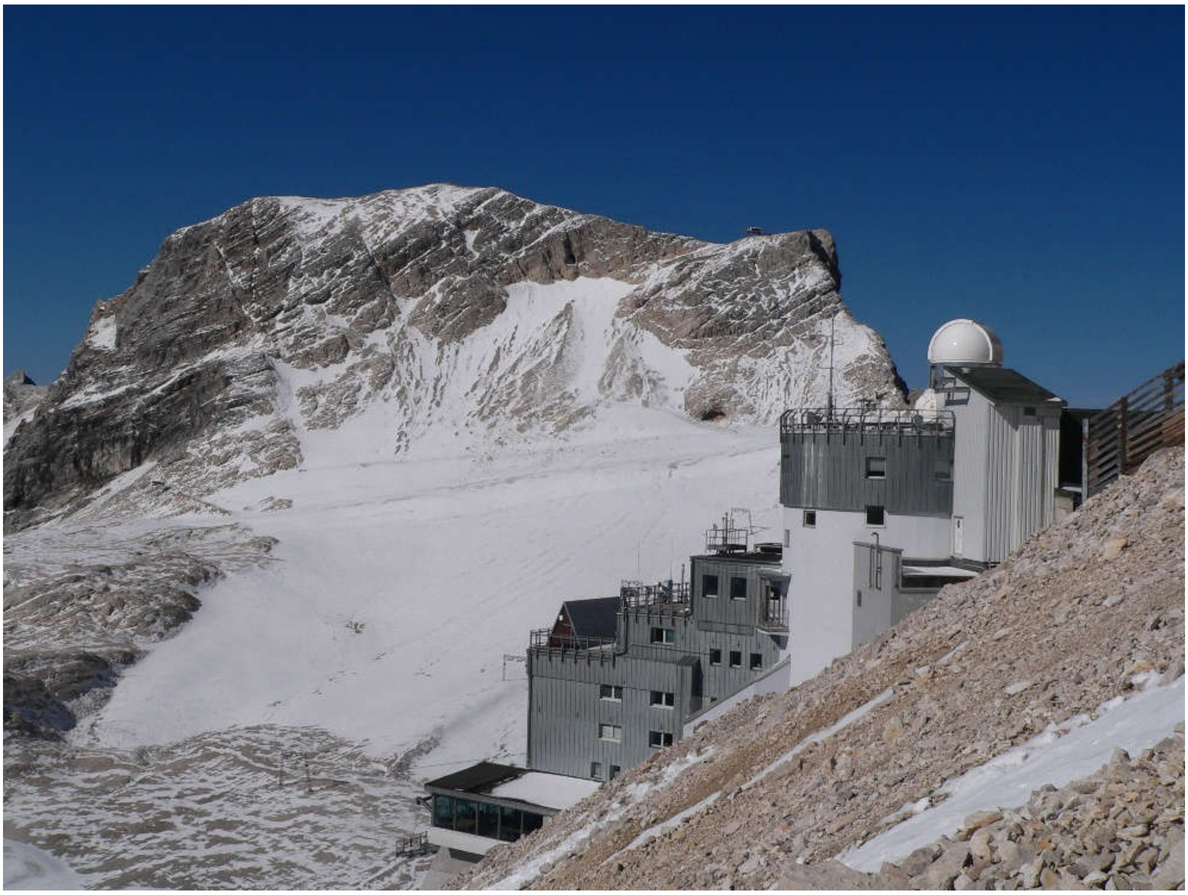

Figure. Schneefernerhaus research station on the southern face of Zugspitze (2680 m). Photo credit Hannes Vogelmann.

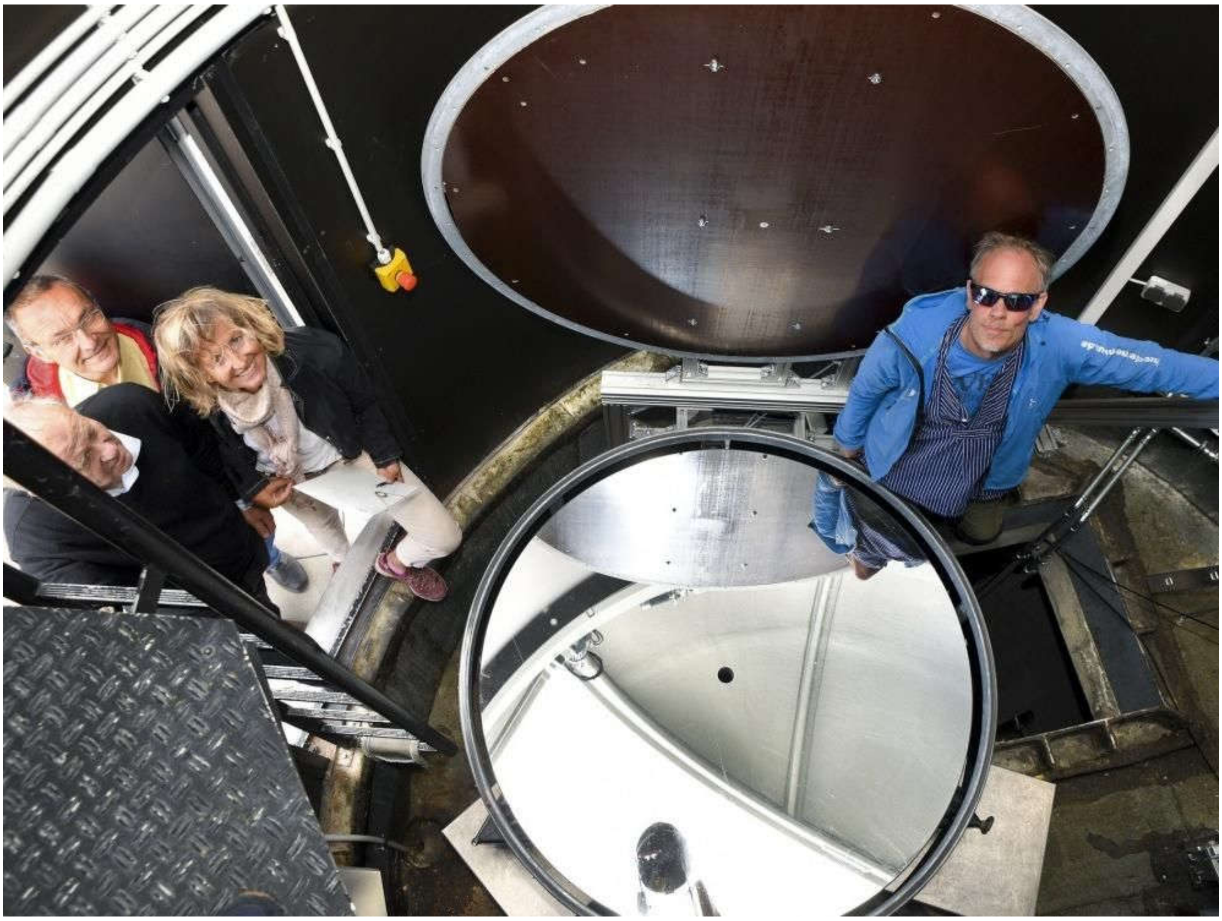

Figure: Dr. Trickl (KIT), Dr. Emmerichs (Coherent), Dipl.B. Wallenta (Coherent), Dr. Vogelmann (KIT) – Project meeting at Zugspitze mountain (2.962m), Top of Germany. UV-Coherent-Laser-System successfully works there for climate research. Photo credit: Coherent

Water vapor is a key atmospheric component with a distribution that is highly inhomogeneous and dynamic. To understand better and to predict weather events and climate changes, scientists need to measure water vapor distributions in real time. In particular, they want to measure water in the troposphere (to ~12 km altitude) and beyond that into the lower stratosphere.

There are various spectroscopy-based methods for remote measurement of atmospheric species, in addition to airborne (e.g., balloon) instruments or high-altitude weather measurement stations. Several laser-based systems have been developed and optimized by Thomas Trickl and Hannes Vogelmann from the Karlsruhe Institute of Technology (KIT, Garmisch Partenkirchen, Germany) on Mount Zugspitze, Germany's highest (2962 m) peak. Both a differential absorption lidar (DIAL) and a high-power Raman lidar were set up at the Schneefernerhaus research station, 300 meters below the summit.

DIAL is a laser-based method that compares backscatter intensity at two closely spaced wavelengths, which here are either on- or off-resonance for a single near infrared (817 nm) H_2O absorption line. The system is based on a narrow-band Ti:sapphire laser system with a pulse energy up to 250 mJ and a Newtonian telescope with 0.65 m diameter. Due to these specifications, the maximum range of their DIAL system is about 12 km.

Raman lidar is an established technique that involves projecting a pulsed laser into the atmosphere and detecting Stokes-shifted Raman backscatter due to water rovibrational resonances. The signal is binned by time, which is then converted into distance (i.e., altitude). Raman scattering intensity has a strongly non-linear inverse dependence on wavelength ($1/\lambda^4$), so to maximize detection range, an ultraviolet laser is preferred, with high pulse energy. The Q rotational branch of the Raman water vapor spectrum is used, which consists of a narrow band of closely spaced lines selected by a 0.75 nm interference filter in the detection system. Any laser source must deliver stable narrowline output to enable efficient signal discrimination. And since the Raman signal depends on polarization, a linearly polarized beam is optimum to deliver quantitative remote data.

For these reasons, the usual choice of laser is the frequency-tripled Q-switched Nd:YAG laser with output at 355 nm and pulse durations of a few nanoseconds. These lasers are commercially available with average powers of ~18 W. This delivers a typical maximum range of around 20 kilometers, but requires signal averaging up to a full night of observation, limiting its utility and temporal resolution.

To avoid this limitation, Trickl and Vogelmann looked for an alternative ultraviolet laser source. Excimer lasers produce the highest pulse energies and highest power of any ultraviolet laser. They also have a pulse length of a few nanoseconds. Both scientific and industrial models are available but the industrial versions have the highest power. These xenon chloride (308 nm) lasers are optimized for precision materials tasks in the display and electronics industries, including silicon backplane annealing and laser lift-off (LLO). They feature excellent pulse to pulse energy and beam stability. However, stringent control of the output wavelength and linewidth is not needed for materials processing.

The Zugspitze group acquired an industrial excimer from Coherent* with pulse energies up to 1 Joule at repetition rates up to 350 Hz. They then modified this laser to provide the narrow linewidth and wavelength stability that Raman lidar requires. Trickl explains, “We first customized the laser to obtain linearly polarized narrow-line output pulses with reduced divergence. Specifically, we extended the cavity to allow us to insert a thin-film polarizer and a tilt-tuned intra-cavity etalon; this etalon allows us to lock the laser wavelength to within 0.025 nm using a calibrated spectrometer. This gives us narrow-line emission with an average power of 180 W, which is 10 times higher than strong 355 nm systems. We also use a signal collection mirror with 4X larger area, so our system provides a S/N increase of about 40X compared with 355 nm instruments used elsewhere.”

Incredibly, even with nine decades of dynamic range—achieved by reducing the photon background to about 1 count per vertical bin (50 ns or 7.5 m) an hour—the system operation is still being optimized. Already, Trickl and Vogelmann can measure water vapor to 18 km altitude with a vertical resolution of less than 300 meters, and to an outstanding 22 km in altitude with 1 km resolution. And 1-hour integration times represent a significant reduction over the past. As a by-product, the system is expected to yield temperature measurements to more than 80 km altitude. The temperature will be derived in a standard procedure from the atmospheric density that governs the backscatter signals.

**This laser is a LAMBDA SX which has since been discontinued by Coherent and replaced by the more cost-effective LEAP laser.*

Coherent Reference Customers:
KIT – Dr. Trickl, Dr. Vogelmann, www.kit.edu