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LIDAR: water vapour in the third dimension

In order to further improve weather forecasting, meteorologists are interested in the third dimension because weather "takes place" in high altitudes. Thanks to the Lidar observation system, developed by the Ecole Polytechnique Fédérale de Lausanne (EPFL), humidity in the atmosphere can be monitored automatically and continuously up to an altitude of 10-15 kilometres.

How does it work?
Lidar is an acronym for «Light Detection and Ranging». It works according to the same principle as radar, however, it uses electromagnetic waves that are normally in the ultraviolet to near infrared spectral range.

The laser: at the Aerological Station Payerne the Lidar laser source generates 30 laser pulses per second, each lasting some nanoseconds, each with at a wavelength of 355 nm. At the exit point a configuration of prisms and lenses is arranged to direct the laser beam vertically and to expand it to a width of 15 cm: this beam meets eye-safety requirements and its parallel alignment is optimised. At an altitude of 1 km the size of the beam is approximately 25 cm.
During its journey through the atmosphere the light beam interacts in various ways with solid and gaseous particles suspended in the air. Every water molecule encountered by the beam back-scatters part of the laser light and by doing so the wave length is modified. This modification - the Raman effect - is specific to individual molecules: for water the Raman back-scattering is measured at 408 nm (for an excitation at 355 nm).

The telescopes: in the Lidar lab a configuration of five telescopes, each with its optical axis aligned parallel to the laser beam, receives the back-scattered radiation. The light collected by these telescopes is focused at the entrance point of optical fibres that enable the "transport" of this light from the telescopes to a spectral separating unit. Each telescope concentrates the light, including the sunlight. It is therefore necessary to separate the sunlight component, which is an important source of noise, from the Raman light. A light detector is placed at the exit of the spectral separating unit. This so-called photomultiplier transforms the incoming light into an electric signal which is then digitalized and analysed.

The Lidar signal: based on the intensity $P(R)$ of the electric signal, the quantity of water molecules can be calculated at any particular moment by the acquisition system. Since the speed of light is known, the time which elapses between the instant a laser pulse is released from its light source to the moment when a light pulse is received on the photomultiplier makes it possible to accurately calculate the altitude R, where a specific concentration of water molecules has been observed. In order to take into account the actual pressure of the analysed air mass, a second back-scattered Raman signal, at the wavelength 387 nm, is used. This signal corresponds to the «signature» of the nitrogen molecule: the ratio water-to-nitrogen between the two Lidar signals is the key to determining the water vapour concentration in the probed air volume.

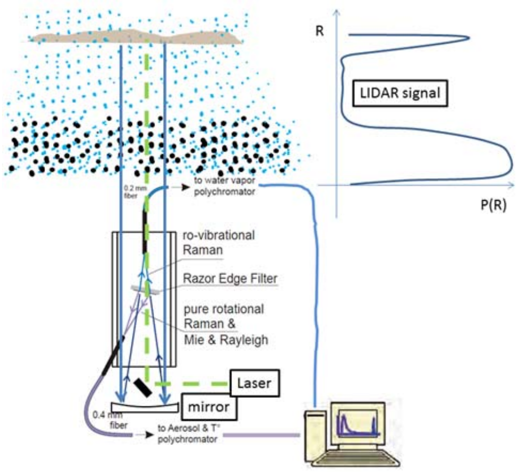

Figure 1
Diagram showing the principles of the Lidar system (see explanations in the text)

The Lidar performance: at each emission of a laser pulse a new altitude-dependent water vapour profile is created. Since the intensity of the recorded signals is weak, these signals have to be accumulated in order to generate a result which is sufficiently precise for meteorological applications: as a standard, one water-vapour profile is obtained every 30 minutes. The resulting time series provides observation data unlike any others meteorological services have had at their disposal to this day. By way of comparison, the Aerological Station Payerne has – over many decades - provided water-vapour profiles by radiosondes twice daily.

The Lidar system measures continuously, but it depends on weather conditions: rain, snow or low-cloud cover interrupt Lidar measurements. In such cases the installation goes into stand-by mode. Taking into account the climate situation of the Payerne site, the Lidar system is in operating mode two thirds of the time over the year.

An ideal complement to the MeteoSwiss observation systems

At the Aerological Station Payerne the Lidar water vapour measurements are an essential element in climate monitoring in the vertical dimension. This development and this progress in the field of measuring instruments perpetuate the skills and know-how for which the Payerne site is known. Here local observations (the surface network SwissMetNet, the Baseline Surface Radiation Network) are combined with observations in the free atmosphere by sounding balloons and remote sensing (radar measurements, micro-wave measurements, GPS).

For the new high-resolution weather forecast models run by MeteoSwiss, the continuous monitoring of water vapour in the free atmosphere provides an input that has never been available before: Lidar opens up new perspectives in the constant improvement of weather forecasts by numerical models.

On an international level, this installation is a demonstrator awaited by the World Meteorology Organisation (WMO) and its Commission for Instruments and Methods of Observation (CIMO): it constitutes a modern alternative to radiosonde monitoring and is a unique method for the validation of satellite observations. This instrument complements the reference measurements of the Aerological Station, with the aim of establishing the Payerne site as one of the few observatories in the world with a WMO mandate for the survey of climate change in the free atmosphere.

After a development process of over 15 years in the EPFL laboratories, after the realisation of the only prototype at MeteoSwiss in Payerne which took another four years (2004 – 2008), Lidar became operational at the beginning of 2008. From that moment onward the good performance of Lidar both in terms of quality and availability of data has been facilitated by an agreement ensuring the continued commitment and collaboration of the partners.

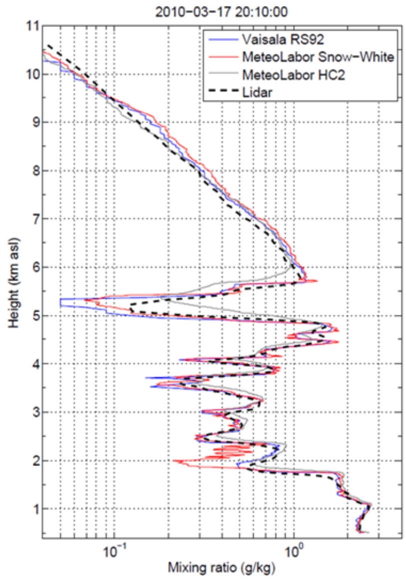

Figure 2

Water vapour concentration in g/kg (grams of water vapour per kg of dry air) in a range of 10 km altitude from the ground is compared using three independent observation systems: SnowWhite and Vaisala RS92 are radiosonde observations – their sensors measure the dew point temperature (SnowWhite) and a change of the capacitive effect, which is dependent on water absorption on the substrate (Vaisala RS92). This result illustrates the calibration quality of Lidar measurements.

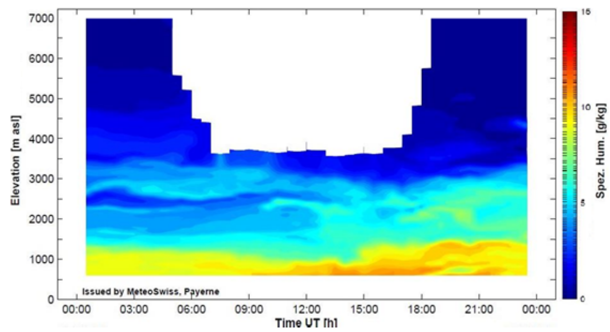

Figure 3

Example of a time series - spanning 24 hours – of the water vapour concentration measured continuously and vertically by the Lidar system at the Payerne site.

Additional Information
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