Vibrating wire sensor for super-cooled liquid water content profiles from small atmospheric platforms

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1. Motivation

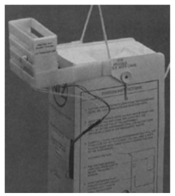
- Super-cooled liquid water (SLW) is a frequent constituent of mid- and high latitude clouds as well as deep convective systems; it strongly influences the clouds' radiative properties and microphysical processes.
- Measurements of vertical SLW profiles are needed for validation of numerical weather prediction models and remote sensor retrieval development but also to improve warnings of icing hazards for airports, power lines, wind turbines, etc.

Exisiting measurement techniques:

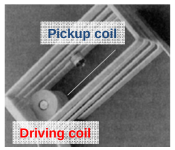
- *In-situ measurements* of SLW are only available from aircraft sensors (mostly hot-wire or optical probes); these are expensive, and require a substantial power supply, and can only be deployed in case studies.
- *Passive microwave radiometer*: without an absorption line for liquid water in the microwave, only liquid water path (LWP) can be retrieved *(Crewell et al., 2009).*
- *Lidar*: Fast saturation of the signal in SLW limits retrieval of multi-layer structures.
- *Multi-frequency cloud radar*: Differential attenuation approaches (*Hogan et al., 2005*) restricted to large SLW amounts; frequencies >90GHz needed to obtain reliable attenuation signal.

2. Vibrating wire sensor by *Hill and Woffinden, 1980*

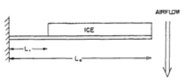
A balloon-borne vibrating wire sensor for SLW was devised by *Hill and Woffinden, 1980*. A piano wire (90x0.6 mm, fixed at only one end) is exposed to the airflow. As super-cooled droplets freeze onto the wire, the resonance frequency decreases. The rate of frequency decrease is proportional to SLW content.



A driving coil excited the wire; the vibration frequency was detected by a smaller pickup coil at the free end, processed by analogue electronics.



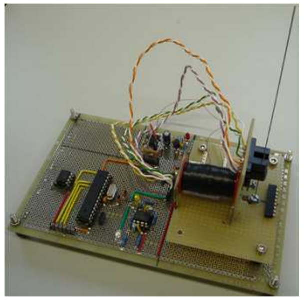
Between 1980 and 1990 the sensor was produced by ATEK Corporation; A comparison of SLW profiles with LWP retrieved from a microwave radiometer proved the reliability of the derived SLW amounts *(Hill, 1994).*

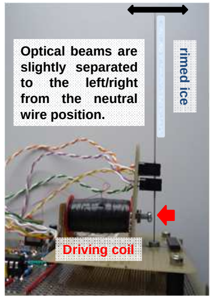


3. 'Next generation' vibrating wire sensor

Motivated by the need for more SLW profiles, in particular for passive microwave radiometer retrieval development, a scientific prototype of an improved disposable and inexpensive vibrating wire sensor has been developed at the University of Cologne. The most relevant improvements to the first generation sensor are:

- Wire diameter reduced to 0.5 mm to increase collection efficiency for small cloud droplets
- Short impulses to maintain vibration at its resonance frequency, with no continous excitation by the driving coil
- Pickup coil replaced by two optical detectors (not exposed to airflow)
- Analogue processing replaced by a microprocessor (AVR)





First climate chamber test: -30°C.

- The wire is given only a short impulse from the driving coil when it is moving towards the coil and crossing the two optical beams which are slightly horizontally separated. This ensures minimal influence on the resonance frequency.
- The optical beams are also used to derive the resonant frequency, which is converted to an analogue (0-5V DC) signal.
- If the vibration stops, the processor automatically restarts an activation procedure until a stable oscillation is restored.

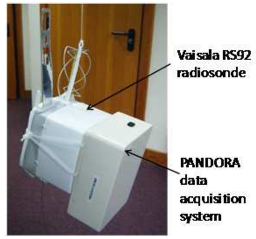
Given the ice-free resonance frequency, f_0, and the measured frequency, f, collection efficiency, ε, wire diameter, D, airflow speed, w, and mass per unit length b_0, the SLW content can be calculated according to Hill, 1994:

$$SLWC = \frac{-2 f_0^{\,2}}{\varepsilon b_0 D w f^3} \frac{df}{dt}$$

The system has been successfully tested in a climate chamber down to -30°C. The resonant frequency changed from 46 Hz down to 40 Hz within 7 min. while the wire diameter increased to 2mm (4x diameter).

4. Summary and Outlook

A laboratory prototype version of an improved SLW vibrating wire sensor has been developed and successfully tested in a climate chamber down to -30°C.



The SLW sensor is intended to work directly with the University of Reading PANDORA data aquisition system (*Harrison et al., 2012*) to allow the SLW sensor to fly alongside a standard RS92 radiosonde.

Next steps:

- Miniaturisation to give a flight prototype, mass reduction (currently ~200g), power optimization (currently 100mA, 9V)
- Further calibration tests in climate chamber and wind tunnel
- First balloon-borne flight tests - ideally, with collocated microwave radiometer and/or cloud radar/lidar observations (e.g. at Lindenberg or Chilbolton site)

Outlook:

- Easy adaption for UAV platforms.
- Combining the vibrating wire SLW sensor with optical cloud sensors (under development at Uni. of Reading)
- improve the range of cloud parameters routinely determined (e.g. for studies on thundercloud electrification or cold cloud microphysics) by combining the SLW sensor with existing sensors for charge, aerosols or electric field strength

To progress towards a flight-ready SLW sensor, technology collaborations are sought with the UAV community.

References:

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