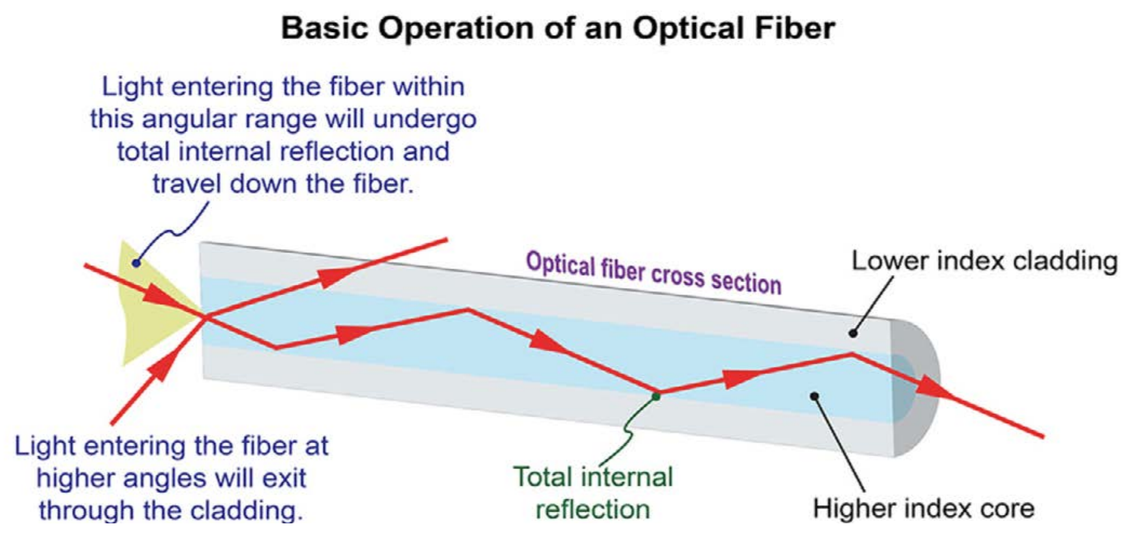
Fiber optic temperature measurement: why, how and examples in water sciences

Benjamin Ballé, M2 IDIL AWARE, benjamin.balle@etu.umontpellier.fr

Electronics and photonics sensors are commonly used in water sciences. The range of application is broad, from the detection of contaminants to the measure of physicochemical proprieties. Since the end of the 20th century, the study of the temperature became more popular and many news applications were discovered. However, temperature measurements present different problems. Usually they are measures done at a precise time and place resulting in difficulty to make spatial and temporal monitoring. Probes such as CTD-divers can be used to monitor the temperature over time but they are expensive and don't solve the spacial problematic. Fiber-optics cables are able to solve these problematics but how does the optical fiber is able to measure temperature and what are the possible applications in water sciences .

What is fiber optic ?

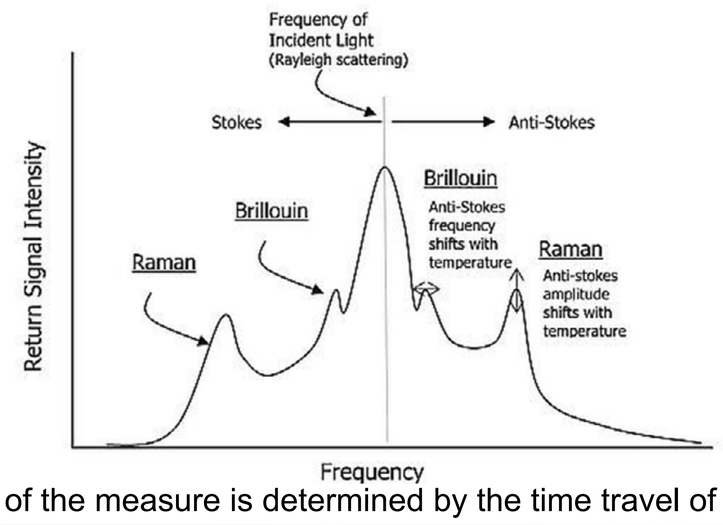
-> Optical fiber is composed of a thin and long fibre made of glass or plastic that allow the passage of light inside.
-> The core is surrended by a coating with a low refractive index that allow a total internal reflection in the fibre



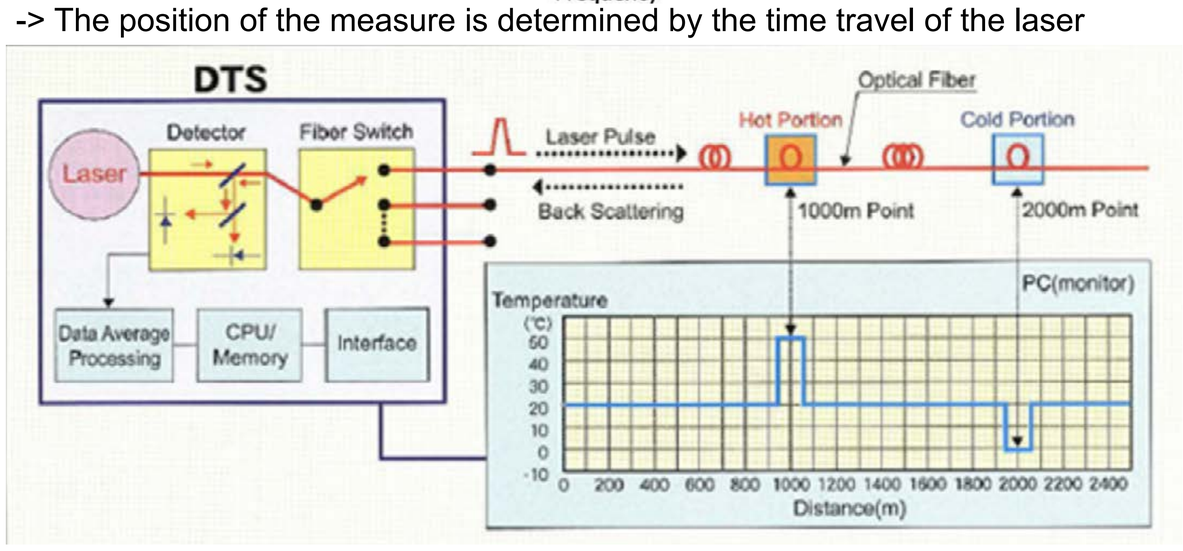
How does optical fiber can measure temperature ?

Distributed Temperature Sensing (DTS)

-> Raman effect is used to measure temperature because the intensity of anti-Stockes change with the temperature.



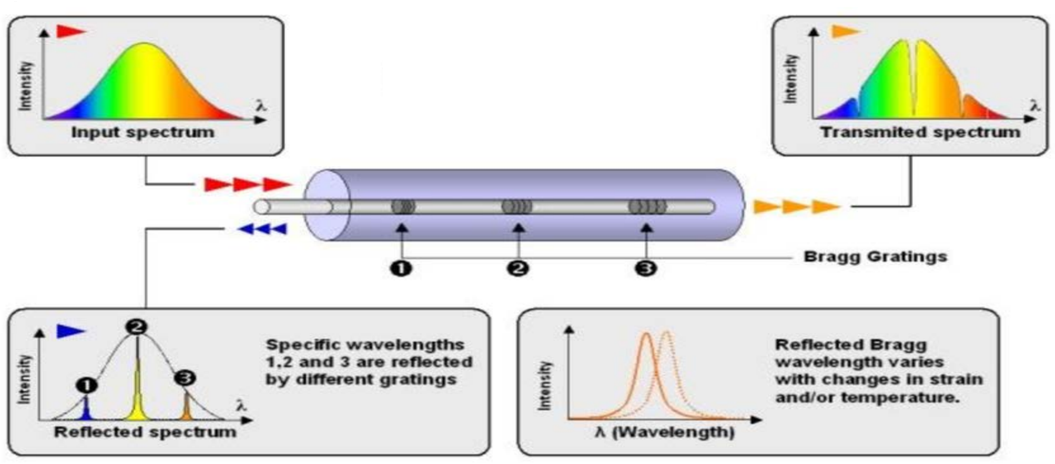
-> The position of the measure is determined by the time travel of the laser



-> Continuous measurement possible over 20km
-> Spacial resolution of usually 1m but can be reduced with specific configuration

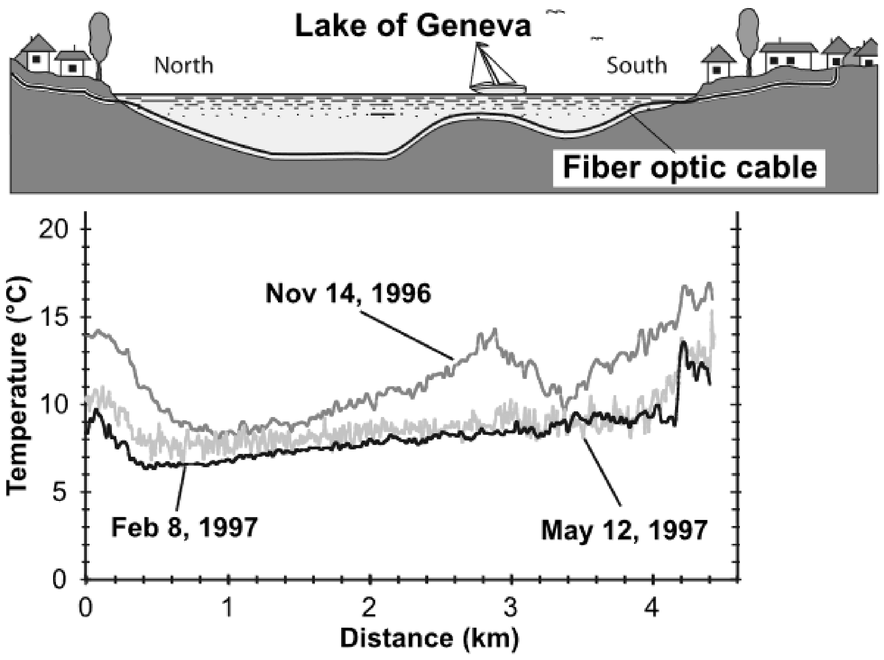
Fiber Bragg gratings (FBG)

-> Inside the core, Bragg reflector are placed.
-> Spatial resolution and thermal precision usually higher than DTS but more expensive

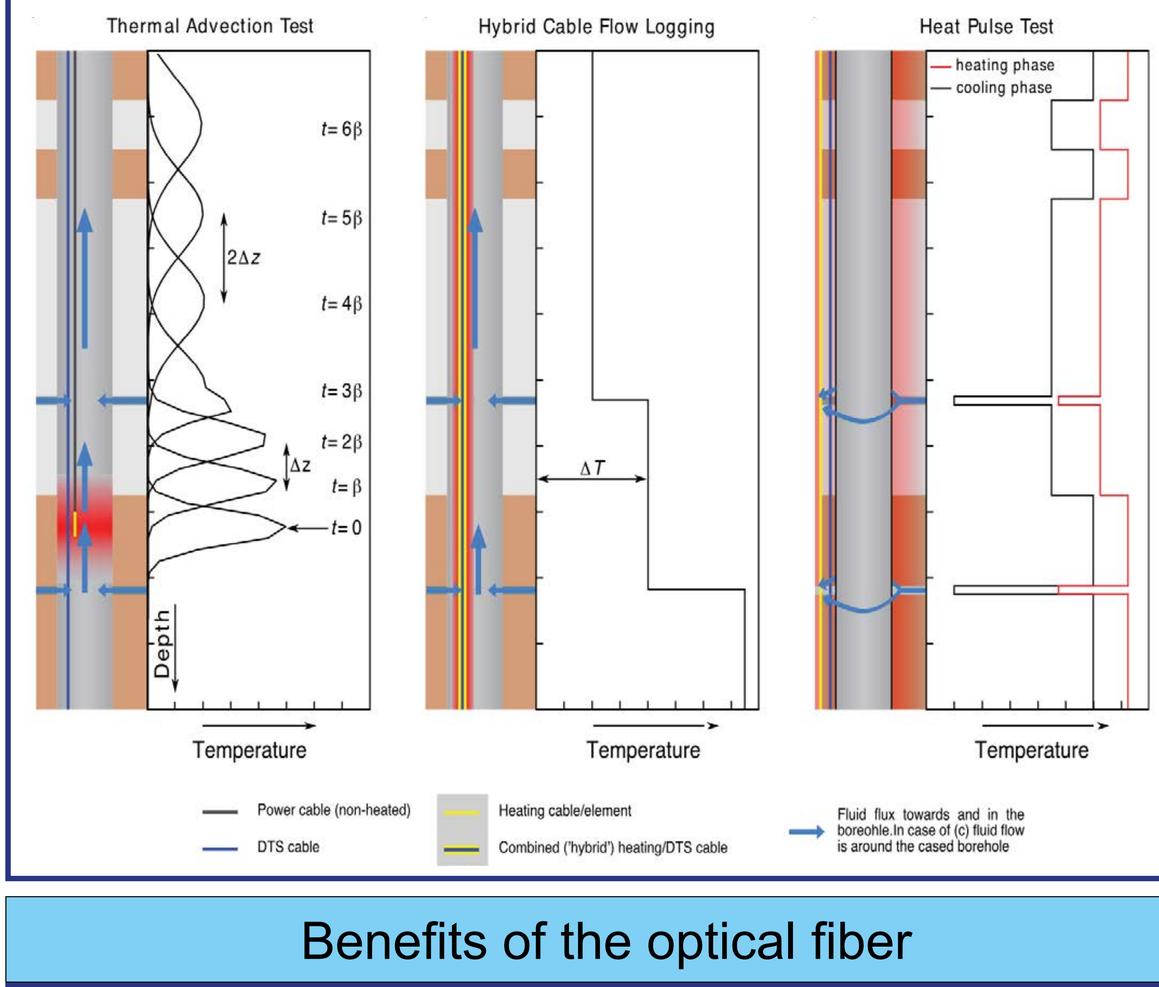


Applications in water sciences

-> Detection of groundwater springs in river
-> Monitoring of temperature of water at the bottom of a lake



-> Passive borehole monitoring
-> Dam leaking monitoring
-> Thermal tracer test with estimation of groundwater velocity
-> Underground river monitoring
-> Active borehole monitoring



Benefits of the optical fiber

-> Possibility to do temporal monitoring
-> Usuable in spacial monitoring with a high spacial resolution
-> Thermal precision around 0.2 °C and can be reduced to 0.01 °C
-> Cheaper than using a probe network
-> Possibility to use the fiber to measure other parameters : water level, pressure, flow, speed of water or conductivity
-> Low operating costs after installation

References :

Bense, V. F., Read, T., Bour, O., Le Borgne, T., Coleman, T., Krause, S., Chalari, A., Mondanos, M., Ciocca, F., & Selker, J. S. (2016). Distributed Temperature Sensing as a downhole tool in hydrogeology. Water Resources Research, 52(12), 9259–9273. https://doi.org/10.1002/2016WR018869

Domanski, M., Quinn, D., Day-Lewis, F. D., Briggs, M. A., Werkema, D., & Lane, J. W. (2020). DTSGUI: A Python Program to Process and Visualize Fiber-Optic Distributed Temperature Sensing Data. Ground Water, 58(5), 799–804. https://doi.org/10.1111/gwat.12974

Drusová, S., Bakx, W., Doornenbal, P. J., Wagterveld, R. M., Bense, V. F., & Offerhaus, H. L. (2021). Comparison of three types of fiber optic sensors for temperature monitoring in a groundwater flow simulator. Sensors and Actuators A: Physical, 331, 112682. https://doi.org/10.1016/j.sna.2021.112682

Quattrocchi, G., Berri, P., Dalla Vedova, M., & Maggiore, P. (2020, January 1). Optical fibers applied to aerospace systems prognostics: Design and development of new FBG-based vibration sensors.

Selker, J., Thévenaz, L., Huwald, H., Mallet, A., Luxemburg, W., van de Giesen, N., Stejskal, M., Zeman, J., Westhoff, M., & Parlange, M. (2006). Distributed fiber-optic temperature sensing for hydrologic systems. Water Resources Research, 42. https://doi.org/10.1029/2006WR005326

Suárez, F., Hausner, M., Dozier, J., Selker, J., & Tyler, S. (2011). Heat Transfer in the Environment: Development and Use of Fiber-Optic Distributed Temperature Sensing. https://doi.org/10.5772/19474