SENSORS AND SCIENCE

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WHAT IS A SENSOR?

Without data you're just another person with an opinion.

W. Edwards Deming
HOW ARE SENSOR DATA USED?

• Data are used to inform a theoretical model
• Errors in the data result in errors in the model prediction
• You need to understand your sensor to understand the results
• Often we aren’t even measuring what we want to know
WEATHER STATION

• We measure:
  • Wind speed
  • Wind direction
  • Humidity
  • Rainfall
  • Solar radiation
  • Temperature at 10 heights

• We want:
  • Infiltration rate of water to rock
WORKFLOW

Actually “sensing” is sometimes a small part of the process

1. Deciding what to measure, how often, how to do it
2. Handling the data
3. Interpreting the data
4. Regretting step 1.
STAGES OF SENSOR GRIEF

1. **Shock and Denial**: this sensor is amazing I can measuring anything!
2. **Pain and Guilt**: how much time do I have to spend on this thing, I have homework to grade!
3. **Anger**: aarrrgh! I keep getting an error code!
4. **Bargaining**: if I can just get past this code I swear I will never do another installation
5. **Depression**: it will never work
6. **Testing and Reconstruction**: OK, I think it’s working now
7. **Acceptance**: look at these data, I have to install this thing somewhere else!
THE SENSOR EXPLOSION

• Sensors have become cheaper and more sophisticated
• Data storage is also cheaper
• For example, we can now purchase a UAV-based terrain mapping LIDAR (laser range mapping) because self-driving cars use LIDAR
THE SENSOR EXPLOSION

- The ubiquity of sensors has allowed the advent of “citizen science” where everyone with a cellphone is a sensor station.
- The Myshake project will use accelerometers on cell phones as an early warning system for earthquakes.

Myshake crowdsourcing of seismological data using phone accelerometers:
Noise floor of the phones. Dashed black lines are typical ground motion amplitudes of earthquakes 10 km from the epicenter for various magnitudes. Noise floor for high-quality MEMS sensor (HP MEMS, blue) and a typical force-balance accelerometer from a regional network (BKS in northern California, purple) are also shown (Qingkai Kong et al. Sci Adv)
THE PROBLEM WITH DATA

- The more data you collect, the harder it is to process, store, and interpret.
- Many scientists must become IT specialists.
- Let's look at some examples in hydrology.
HEAT AS A TRACER

• In 2005 we surveyed the temperature of stream near Buffalo. Because groundwater is cold, cold water was used as a tracer of groundwater entering the stream.
• We collected 14 temperature points
• The data and model are plotted on the right

FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING (FODTS)

- FODTS uses backscattered light along a fiber optic cable to measure temperature
- It can measure temperature every ¼ meter, over 10 km, every 10 minutes.
- That’s about 6 million measurements per day.
FODTS IN A STREAM (SHENANDOE RIVER)

- Now we have temperature measurements that are dense in time and space
- Let's have some fun!
GROUNDWATER RECHARGE BASINS

• Recharge basin water heats/cools daily
• Propagation of temperature oscillations can be measured at depth
• Rate of propagation related to infiltration velocity
1. **Mini Anaheim - Horizontal:**
   establish method

2. **Off River Basin - Horizontal:**
   spatial distribution

3. **Mini-Anaheim - Vertical:**
   vadose zone behavior

4. **LaPalma Basin – Horizontal and Vertical**
   lateral flow
MINI ANAHEIM TESTS

- Sooner the temperature shows up at depth, faster the infiltration rate

The FODTS temperatures were analyzed with wavelets to produce infiltration rates (specific discharge).

We could see the clogging of the basin over time, and where it clogged.

SANTA ANA OFF-RIVER BASIN

- 1400 m of cable trenched along Santa Ana River-Side spreading basin
MINI-ANAHEIM VERTICAL

• Direct “pushed” fiber into the ground to 10 m
• Wrapped vertical fiber gave 1:10 increase in sampling resolution (10 cm)
• Installed a pressure, temperature, soil moisture sensors too
VERTICAL TEMPERATURE PROFILES
MINI-ANAHEIM VERTICAL

- Vertical temperature profiles show water backing up behind fine-grained sediment layers
4D DATA MANIPULATION

• Working toward a 3D grid of temperature through time (4D).
• How do you visualize something like this?
• There are software, but how much time should a geology student spend learning Matlab or Python? Is this science?
OTHER APPLICATIONS: HIGH SPEED RAIL

- Fiber optic cable buried in boreholes in the San Gabriel Mountains to map water movement

OTHER APPLICATIONS: GEOTHERMAL ENERGY

• Mapped hot water flowing through a rock fracture to understand geothermal energy exchange

OTHER APPLICATIONS:
GROUNDWATER SEEPAGE TO THE OCEAN

- Where fresh groundwater seeps to the ocean it leaves a temperature signal
- We are planning to deploy DTS on islands where we have done boat surveys

Catalina  Kauai  Moorea (Tahiti)  Easter Island
FUTURE: DISTRIBUTED ACOUSTIC SENSING

• Similar to fiber optic distributed temperature sensing but measures vibrational strain

• Measured 10 picometer/m strain in rock (1 picometer = 1 millionth of micron)

• Collected 1000/sec, over 800 m, every 25 cm
  • 384 million strain measurements / experiment
  • 50 billion measurements / day
CONCLUSIONS

• Sensors are an integral part of natural science and are here stay

• Students need skills in:
  • Graphing, image interpretation
  • 4 dimensional thinking
  • Data handling
  • Basin electronics concepts
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