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Inductive Conductivity Cell: *A Primer on High-Accuracy CTD Technology*

2020 Sea Technology Paper

This presentation is based on:

Inductive-Conductivity Cell: *A Primer on High-Accuracy CTD Technology*

Dr. Mark Halverson • Eric Siegel • Dr. Greg Johnson

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Inductive-Conductivity Cell

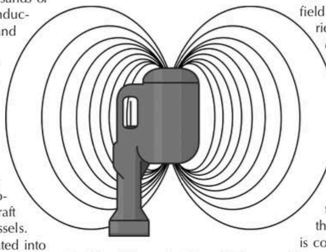
A Primer on High-Accuracy CTD Technology

By Dr. Mark Halverson • Eric Siegel • Dr. Greg Johnson

Conductivity, temperature and depth are core variables used by oceanographers and limnologists to study water properties and dynamics. RBR has been designing and manufacturing precise instrumentation for 45 years and introduced the inductive-conductivity sensor in 2000. Since then, thousands of RBR CTDs with inductive-conductivity cells have been built and deployed.

RBR CTDs have been deployed by major oceanographic centers worldwide into every ocean on Earth, and into the harshest environments, from the abyss to the poles. They have been deployed from many platform types: kayaks, ocean-going research vessels, aircraft and commercial fishing vessels. RBR CTDs have been integrated into ocean gliders, autonomous underwater and surface vehicles, and profiling Argo floats. They are frequently selected as the reliable solution for major citizen science programs.

This article focuses on the RBR CTD's inductive-conductivity cell, including operating principles, unpumped design, accuracy, resolution and stability.



Schematic of the RBR conductivity cell. The curved lines represent conceptual invisible lines of magnetic and electric fields surrounding the cell. The temperature sensor is co-located with the conductivity sensor to measure the same water parcel.

Operating Principles

RBR's conductivity cells function according to Faraday's law of induction. Each cell contains two toroidal coils: a generating coil and a receiving coil. An AC signal is applied to the generating coil, producing a magnetic flux and a resultant electric field, and, finally, a current is induced in the seawater present in the center of the cell. The current in the seawater passes through the center of the receiving coil and induces a secondary current to flow in the receiving coil. The current in the receiving coil is proportional to the resistance of the water, which is inversely proportional to conductivity.

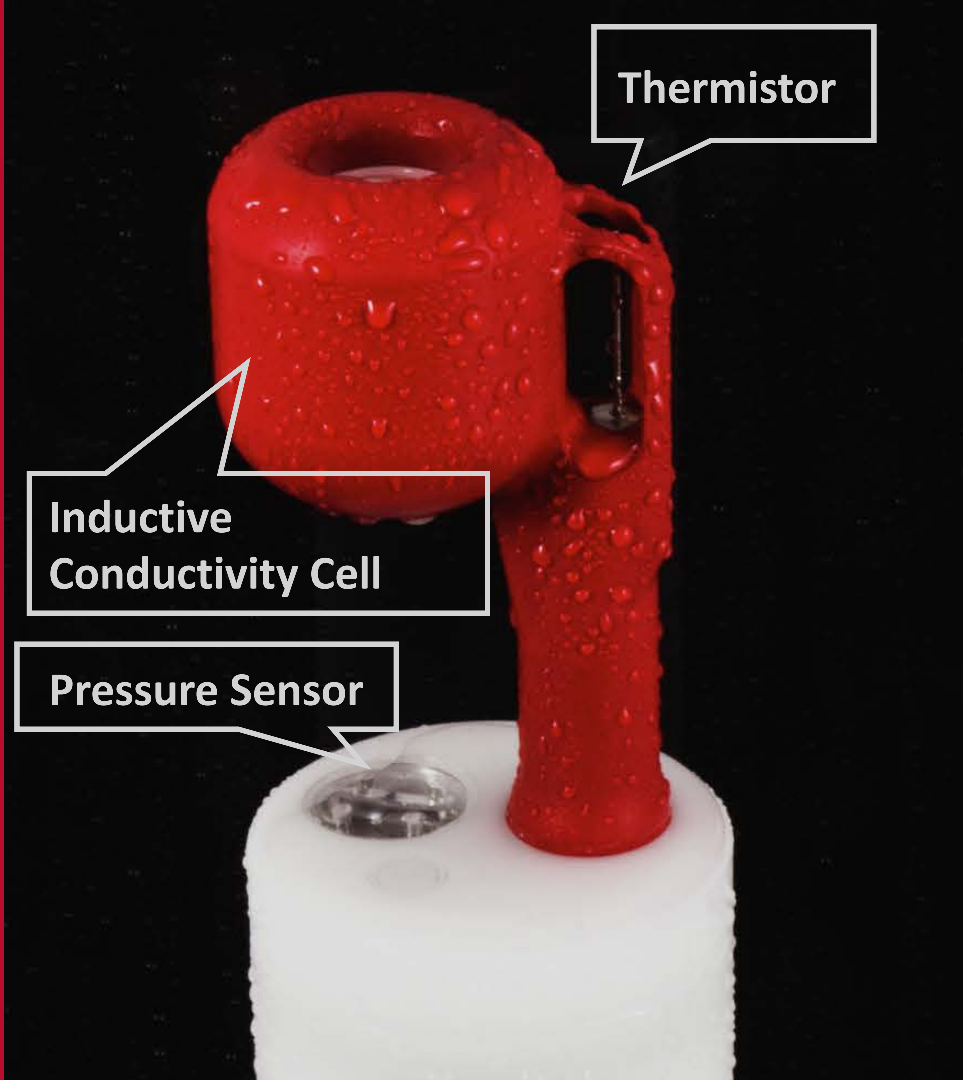
The current driven by the electric field can be conceptualized as a series of closed rings of current traveling through both coils in the conductivity cell, out into the water, then back into the cell. The current rings are most dense inside the cell, and they spread out with distance away from the cell.

Theoretically, the field induced by the conductivity cell extends an infinite distance from the cell. In practice, the majority of the measurement is constrained to the local proximity of the sensor. The high concentration of field lines within the center of the conductivity cell means that most (approximately 80 percent) of the conductivity measurement originates from this region. This local spatial extent of the electric field has implications both for calibration and deployment (described later in Proximity Effect).

Design

The primary RBR conductivity cell has a co-located temperature sensor and thus is frequently referred to as a “combined CT cell.” There are three versions of the combined CT cell, each rated for a different maximum pressure: 1,000 dbar; 2,000 dbar; and 6,000 dbar. The 1,000-dbar version is made from polyoxymethylene and

CTD technology



Conductivity cell for different max pressure rating

Three versions, each rated for a different maximum pressure

750dbar

2000dbar

6000dbar

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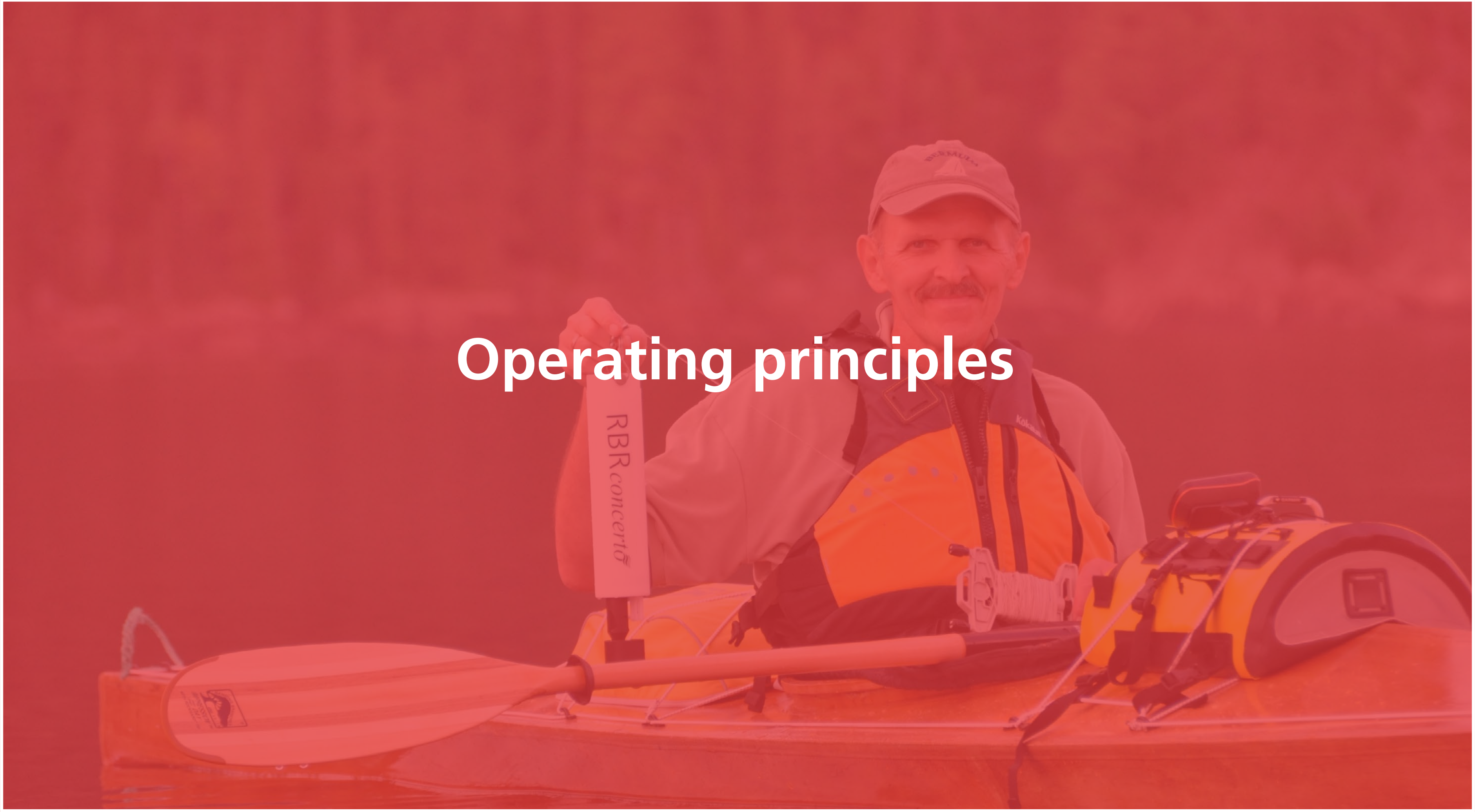
Operating principles



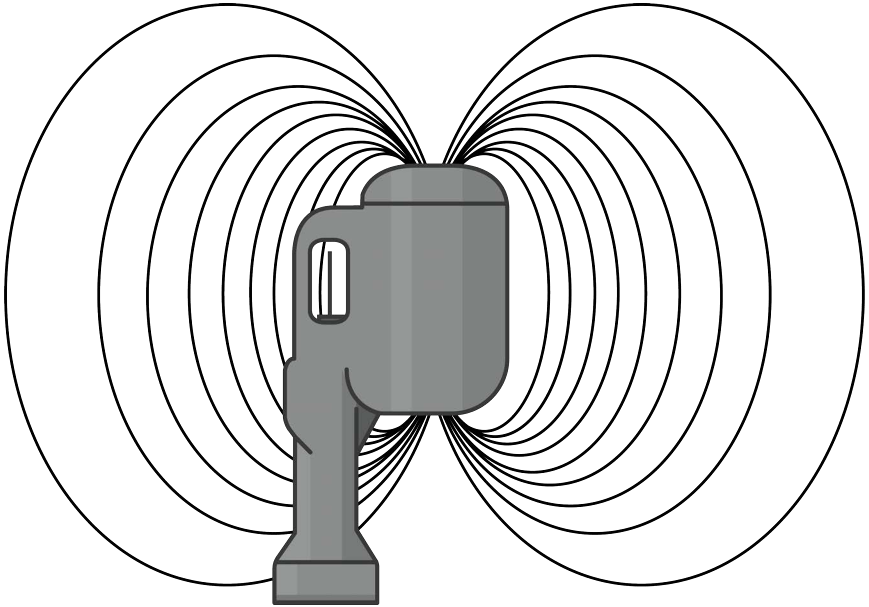
Measurement principle of an inductive conductivity cell

The measurement of conductivity is based on Faraday's law of induction.

- Variable magnetic flux drives a current in a circuit.

RBR uses a "double transformer" design

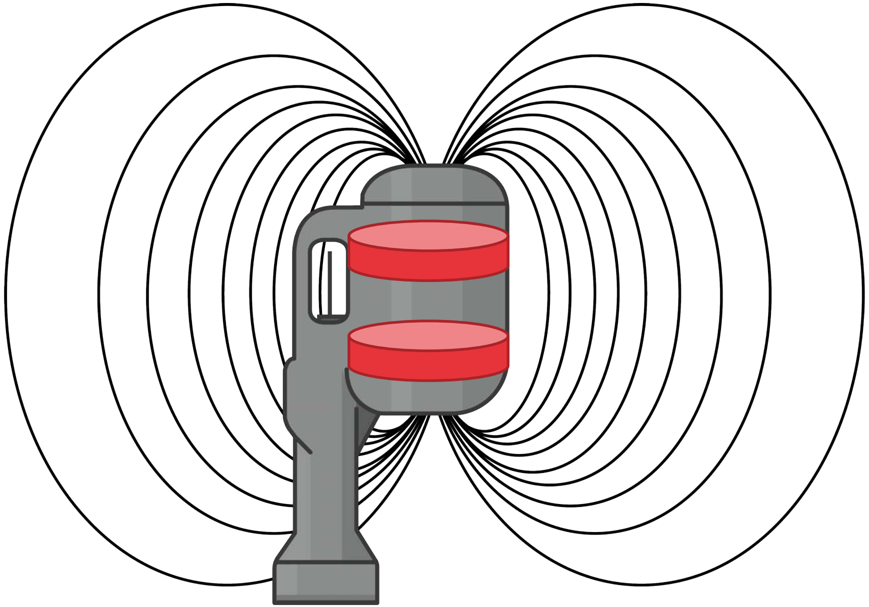
- Two independent toroidal coils
- Basic idea for this introduced 100 years ago:
    - *Piccard and Frivold (1920). *Démonstration de courants d'induction produits sans électrodes dans un électrolyte.*
    - **M. J. Relis (1947), *Electrodeless method for measuring low-frequency conductivity of electrolytes*.



*https://www.e-periodica.ch/digbib/view?pid=ads-001:1920:2::811#271
**https://dspace.mit.edu/bitstream/handle/1721.1/43268/28203965-MIT.pdf?sequence=2&isAllowed=y

Measurement principle of an inductive conductivity cell

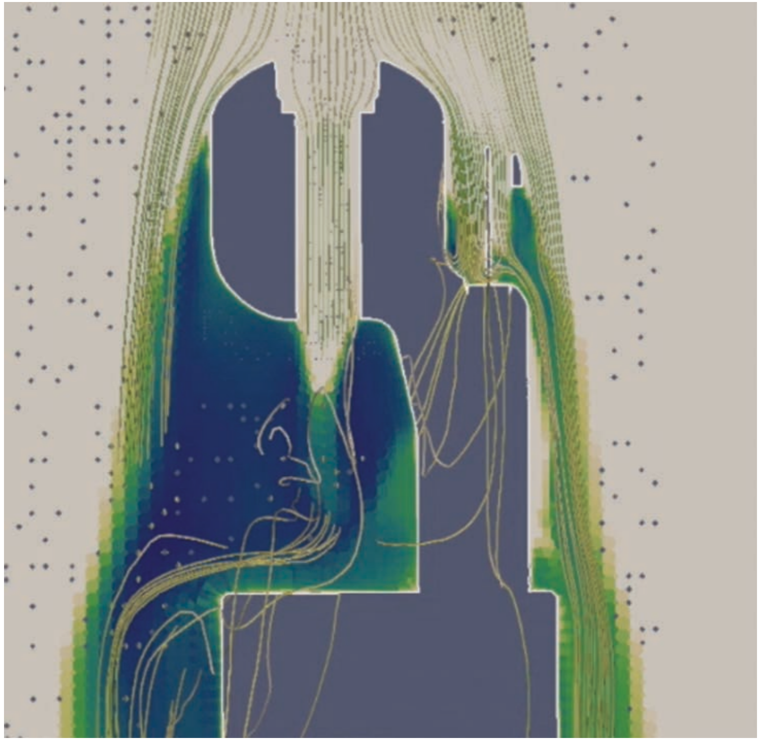
- Drive coil and receive coil
  - Apply an AC current to the drive coil
  - Causes a changing magnetic flux in the generating ferrite
  - Electrical current induced in sea water
  - Changing current in sea water induces magnetic flux in receiving ferrite
  - Changing magnetic flux in ferrite causes AC current in receiving coil
  - Current in receiving coil is proportional to the seawater conductivity



A few pros and cons of inductive conductivity cells

Pros:

- Conductivity cell can be built with a low aspect ratio
- Cell flushes naturally
- No pump required
- Low power consumption
- Acoustically quiet
- Robust
- "Contactless"
    - No metal electrodes
    - Not affected by surface oils



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Proximity effects

Proximity effects

Any material within close proximity of the conductivity cell changes the measured conductivity.

- Recommended to keep objects 15cm from cell
- High bias for conductive material (e.g., stainless steel guard)
- Low bias for non-conductive material (e.g., rope or insulated mooring line)
- Calibration can eliminate proximity effect
  - Instrument calibrated in the guard
  - Float heads calibrated with Iridium antenna and oxygen optode
- Can measure accurate conductivity when cell is 10cm from air-sea interface

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Proximity errors from insulated steel mooring line

75mm clamp

150mm clamp

150mm clamp	<0.0001 PSU error
75mm clamp	0.0025 PSU error
Calibration spec	~0.003 PSU

Accuracy, resolution, and stability

From the RBR data sheets:

Calibration Accuracy

- ±0.003 mS/cm (0 – 85 mS/cm)

Precision

- 0.001 mS/cm

Stability

- 0.010 mS/cm/yr

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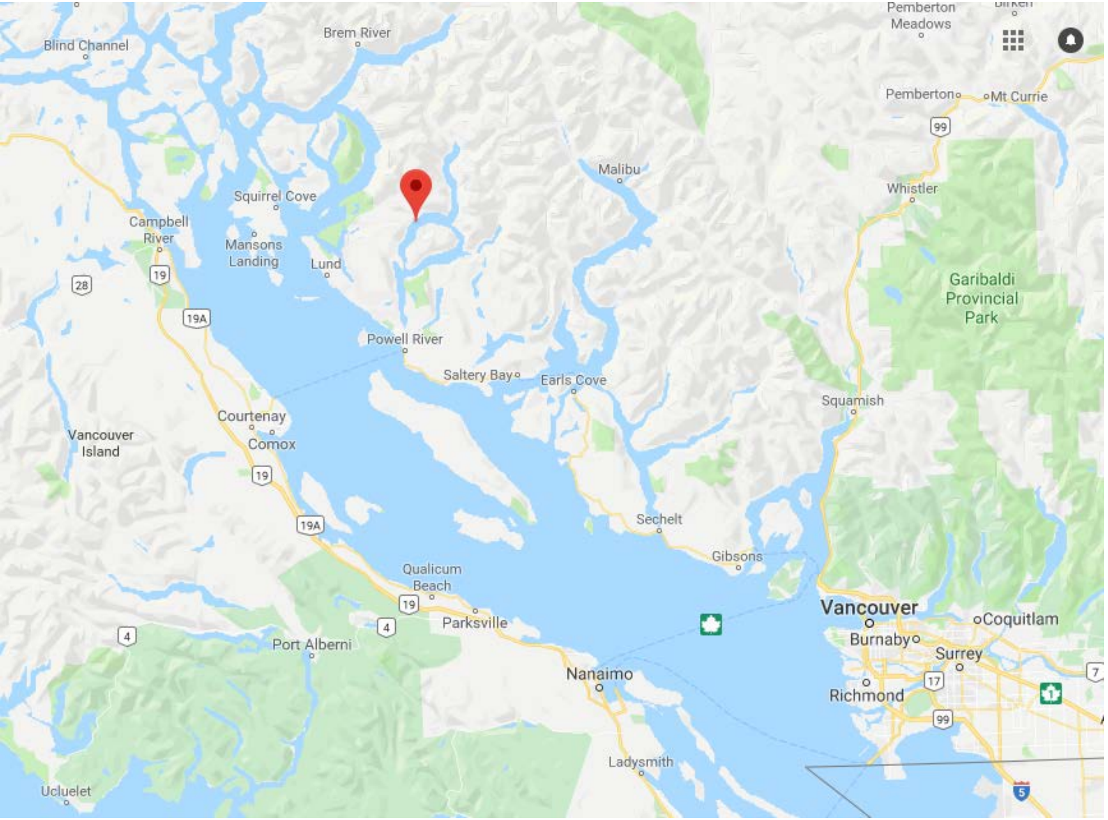
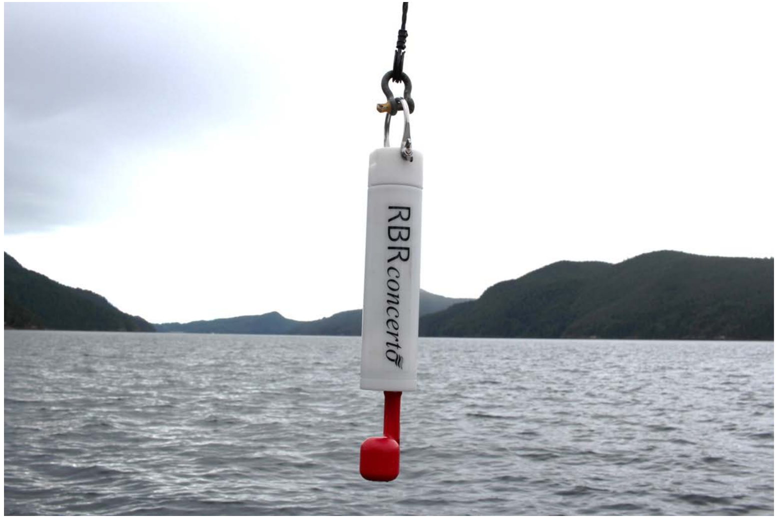
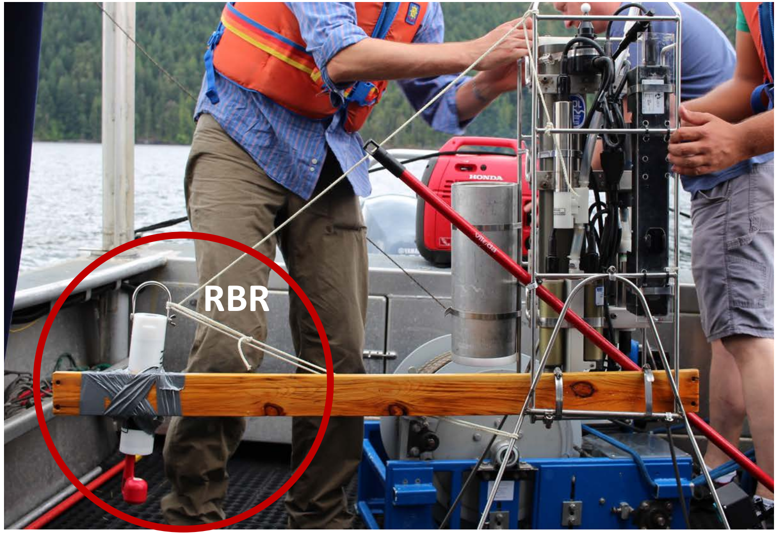
Resolution demo: Powell Lake, BC



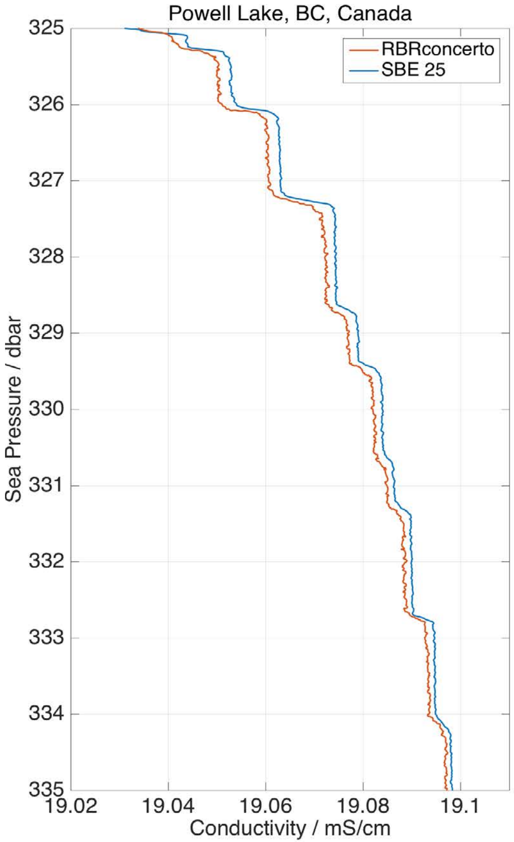


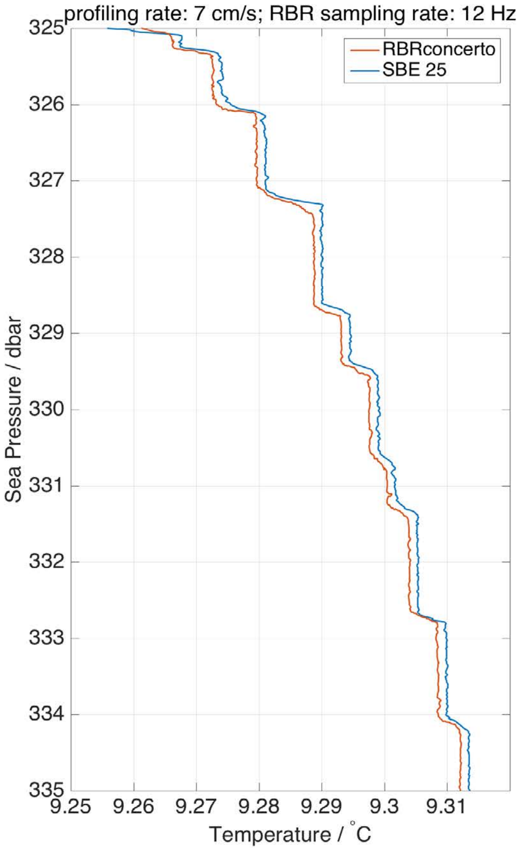


Conductivity resolution: Powell Lake, BC

Able to resolve:

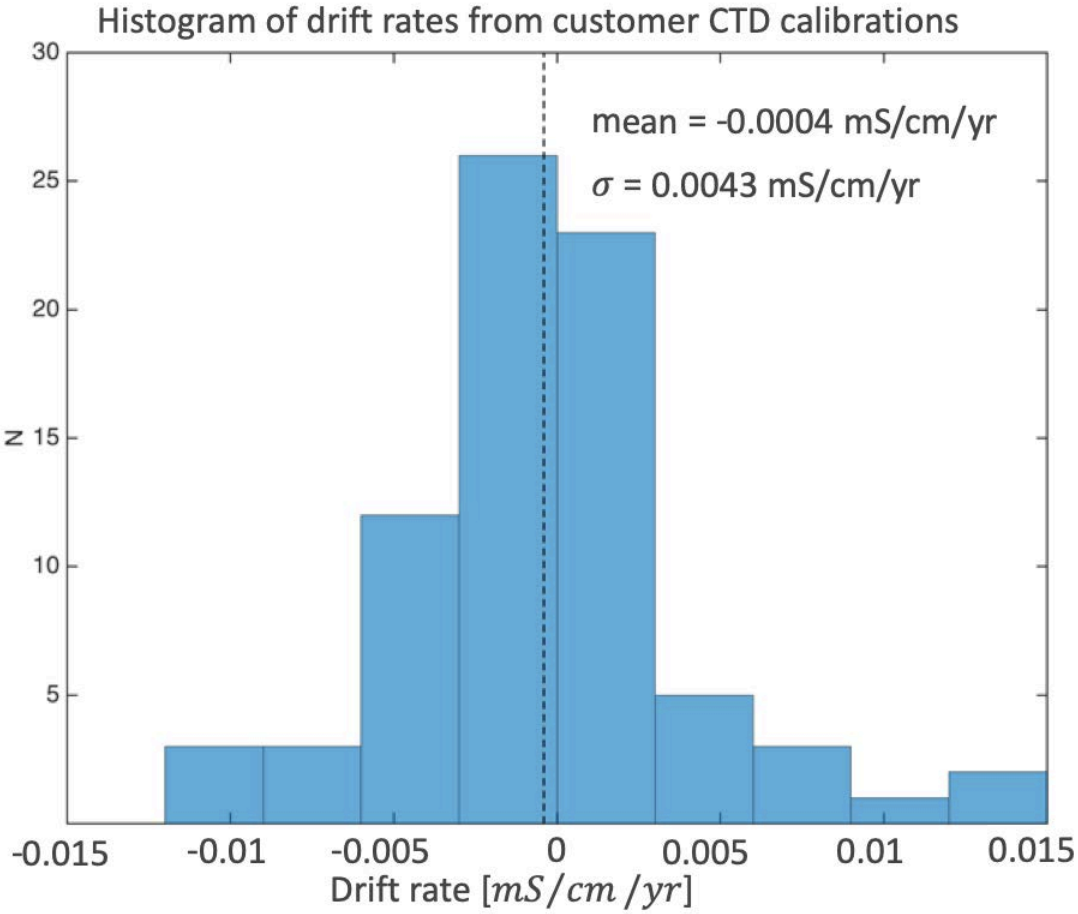
- 1 m thick uniform layers
- 10 cm thick interfaces
- ΔT (adjacent layers) ~ 0.005°C
- ΔS (adjacent layers) ~ 0.002





Conductivity: long-term sensor stability

Calibration lab results: stability



- Mean = -0.0004 mS/cm/yr
- σ = 0.0043 mS/cm/yr
- 70% of instruments have a drift rate of 0.003 mS/cm/yr or less

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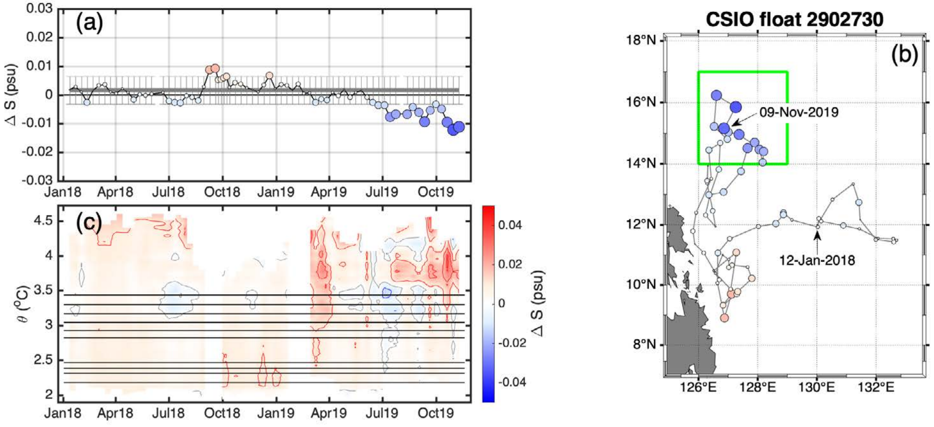
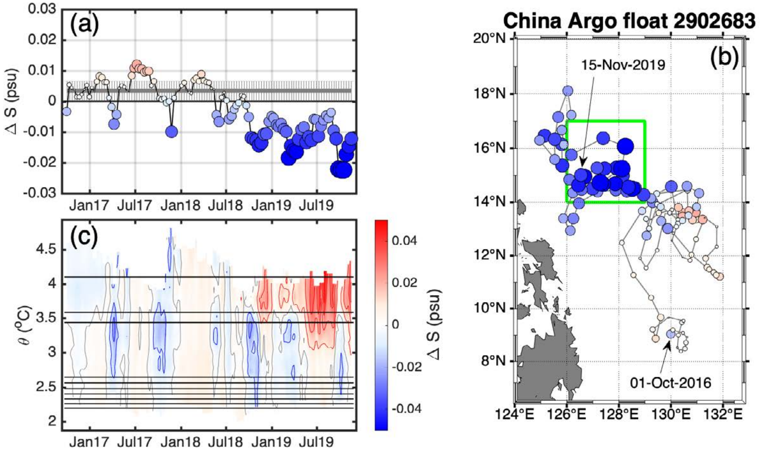
China Argo float w/RBR*argo* CTD:





→ *No* drift or offset relative to standard reference data when analyzed with Owens-Wong stability analysis.

China Argo

Increasing difference between OWC profile fit coefficients near the end of the analyzed period above can be misinterpreted as salinity sensor drift.

Other local floats

However, other floats operating in the same area (2902703, 2902708, 2902688, 2902683, 2902707, 2901545) demonstrate similar trends in salinity offsets.

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Thank you

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