1. The Conductivity Cell Thermal Inertia Correction Problem

- CDI salinity accuracy depends on knowing conductivity sample temperature. A 0.001°C error in sample temperature implies a ±0.01% error in salinity inferred from conductivity.

- Conventionally, response to a step change in temperature of seawater filling a conductivity cell has been modeled by a decaying exponential of amplitude p with decay time constant T. The constants p & T can be chosen empirically & independently, usually to electron density over time & to match T5 variability between downward and upward profiles through nominally identical water types. This approach was introduced by Lueck & Polk, 1992, based on a model of radial thermal exchange within a hollow cylinder developed by Lueck, 1966.

- A wide variety of combinations α & T appear in literature, varying by a factor of two or more from the same cell geometry and cell flushing rate, as shown in Table 1. The conducting cell is modeled as a hollow cylinder with radial heat flow, and the wall temperature change is governed by a heat equation with boundary conditions specified by the cell's geometry and the thermal properties of the cell materials. The response to a step change in seawater temperature is modeled by a decaying exponential with decay time constant T.

2. Radial Heat Flow in a Composite Hollow Cylinder

- Flushing determines the temperature of water within a conductivity cell outside a thermal boundary layer in contact with the cell inner wall. The temperature of the radial boundary layer fluid influences the average temperature within the cell, which conductivity is sensed. Similarly, a boundary layer surrounds the protective jacket, itself surrounding the glass portion of the cell. Heat transfer across the boundary layers is determined by the cell configuration and the cell flushing rate, which is expected to be exponential for a long period of time. Heat flow through the glass portion of the cell can be modeled as a heat equation with boundary conditions specified by the cell's geometry and the thermal properties of the cell materials. The response to a step change in seawater temperature is modeled by a decaying exponential with decay time constant T.

- The density overturns and/or to match T-S variability between downward and upward profiles through nominally identical water types. This salinity is inferred from conductivity. Biot compared to that for the jacket.

3. Response to General Forcing

- From the Fourier Transform of impulse response, the equation governing the contribution by the i-th normal mode to cell wall temperature departure from that forced by selection (cell flushing) is $\frac{d^2 T_k}{dx^2} + \frac{1}{T} \frac{dT_k}{dx} = -\frac{1}{T} \delta(x)$, where $T$ is the decay time constant, and $\delta(x)$ is the modual form.

- The product $a_kT_k$ describes the temperature anomaly at the core wall induced for each mode by a steady-state temperature rate of change (constant $\frac{d}{dt}$). The sum over the greatest 5 modes (at right) captures 99% of the infinite sum, the product with temperature rate of change changing the offset between $T_k$ and $T$. This product formula plays a critical role in the analysis of different heat transfer mechanisms.

- The product of $a_kT_k$ with the cell volume fraction contained in the thermal boundary layer adjacent to the core wall gives $a_k$ the amplitude of the average temperature change in the core induced by diffusion through the heat solid portions of the cell by each mode.

- The response to intermitent sharp changes in temperature is less sharp change in cell averaged temperature followed by decay to the anomaly associated with the mean rate of change. Decay is controlled by the time scale of the first normal mode, rapidly ~0s or more.

- Since flushing temperature rate of change is induced principally by CTD encounter rate with the vertical profile of temperature, a thermal inertia correction $\Delta T = \sum_i a_iT_i$ describes the anomaly magnitude induced by its rate vs a throughput of another's strength.

- The thermal inertia correction thickness $\delta \approx 10$ cm for a pump-binned CTD lowered at 304 m/hr, while it is ~10 cm on a un-pumped CTD on a glider or even ~0.1 cm vertically (profile of a seaglider).

- Despite being flushed more than 10 times faster, a wire-lowered pump-binned CTD requires roughly the same saliency thermal correction as an un-pumped CTD on a glider running at 1.1 m/s through the ocean.

4. Application to Wire-lowered SE89 CTD

- Uncorrected temperature salinity curves from downcasts are consistently more saline that from up casts regions of stable temperature stratification. Applying the standard correction recommended to reduce signal processing error, errors are reduced by >5%.

- Down cast T-S curves from different corrections have different slopes within the thermocline, differing by 0.005°C in salinity.

5. Application to a spot-sampling CTD on a float

- Many WCBAC float-CTDs use CTDs that pump rapidly for 5-10 min before sampling, then turn off as they do not require sampling when a flushing signal is present. During intervals between pumping, the conductivity cell is unflushed and the cell wall, the glass/poly boundary temperature profile, causes the cell wall temperature to lag the exterior by a few tenths of a°C. Cell average temperature rises quickly when pumping starts because the thermal boundary layer thins, then slowly rises more at low flux with a decay scale ~30 s. Sometimes a flux of 20% of CTD's output can be understood by vertically advection of salinity from the main water column with an upwelling jet (heavy dashed magenta curve for a simulation of spot-sampling based on a wire-lowered CTD near Hawaii).

- Systematic underestimation of salinity by ~0.01 implies overestimation of fresh water in the top 50m by ~15%.

6. Application to an un-pumped CTD on a glider

- Thermal inertia correction for un-pumped CTDs requires knowledge of the cell flushing rate. Laboratory experiment and theory show that flow rate is related to vehicle speed $U$ through cell length $L$, cell radius $r$, kinematic viscosity $\nu$, and damping coefficient $C_d$ by $U \approx \frac{C_d}{L} \cdot \frac{L}{r} \cdot \frac{\sqrt{\nu}}{r}$.

- Vehicle speed is determined via a real time mass flow, observation, pitch and buoyancy (Eriksen et al., 2001).

- The glider number counting parameter $\Delta$ can be adjusted to find the best match between salinity profiles inferred from successor casts and data phases of glider travel, giving a sufficiently uncorrected correction for variable tons of salinity.

- Avoiding the use of CTD pump roughly doubles Seaglider endurance and range, effectively halving operational cost.

References


