C-sense pCO_2 Sensor

S-0163
Revision B

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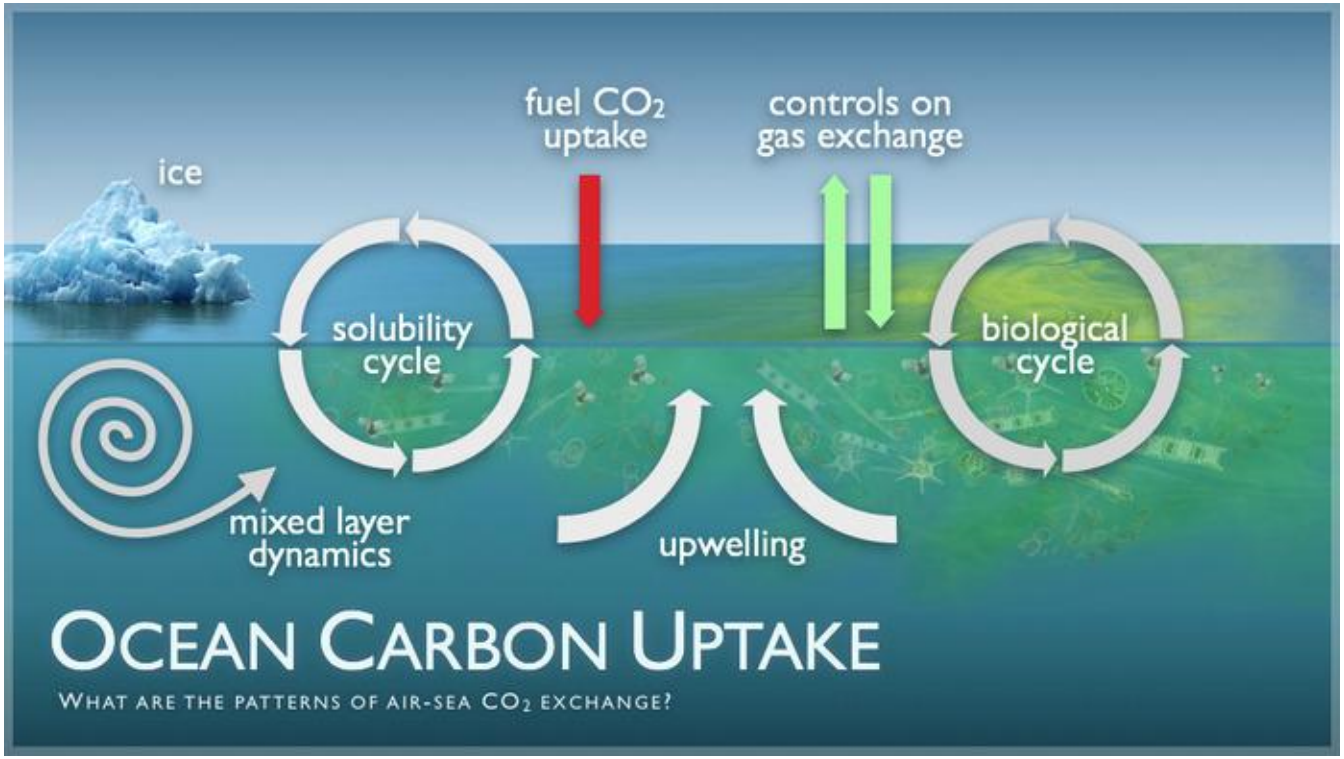
pCO_2 Overview

- pCO_2 – is the partial pressure of CO_2 in a given gas sample.
- In air, pCO_2 is ~400-500 ppm (dependent on location, true nature ~400 ppm, in and near urban areas 450-500 ppm)
- 400 ppm equals 0.04% (400/1,000,000)
- Water will always be moving towards 400-500 ppm when in contact with the atmosphere

pCO_2 Overview



http://www.pmel.noaa.gov/co2/file/Ocean+Carbon+Uptake+Image

This represents open ocean only - many other sources and sinks of CO_2

pCO_2 Overview

- Land sources
  - Rivers and runoff
  - Organic matter decay
  - Dissolution of carbonate rocks
  - Industrial water discharge
  - Wastewater discharge
- Sediment sources from bacteria, diagenesis
- Biological respiration
- Volcanic sources

pCO_2 Overview

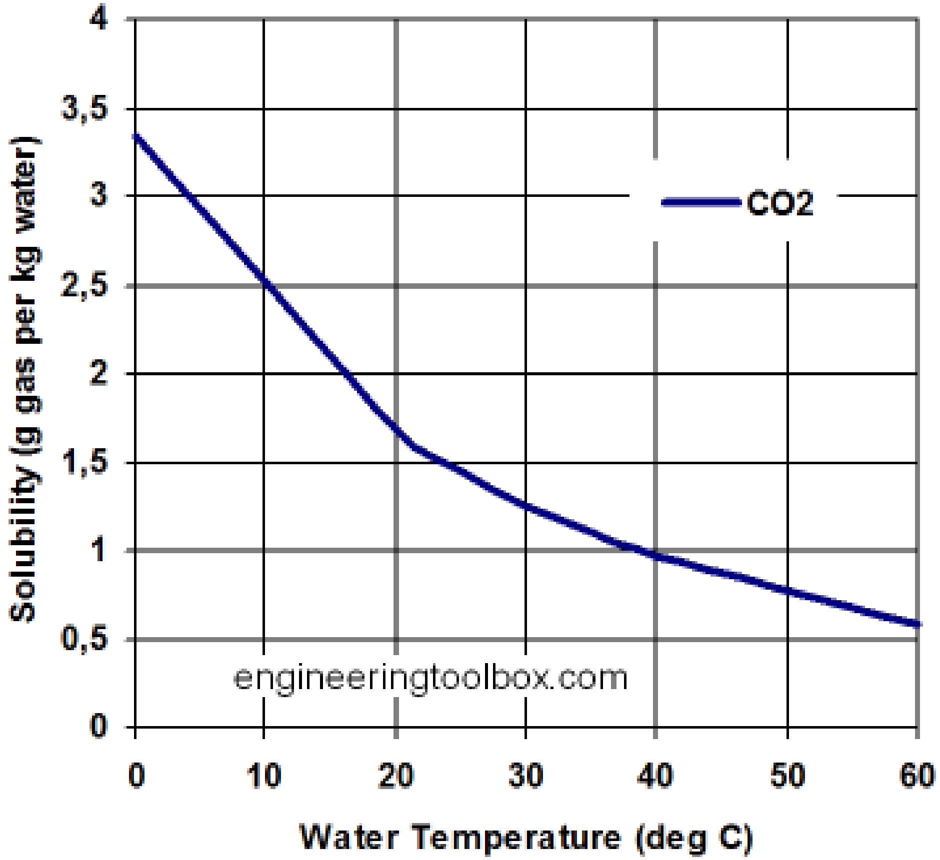
- Gaseous CO_2 dissolves in water according to Henry's Law of Solubility:

  $pCO_2 = [CO_2]aq$ / Solubility

- Where pCO_2 is in fractional form – multiply by 1 million to yield pCO_2 in ppm
- Solubility coefficient is dependent on temperature
- Minor effect of water depth and other constituents such as salinity

pCO_2 Overview

- Solubility inversely related to temperature
- ppm units of the C-sense are for the gas phase, not dissolved phase
- **Some use ppm units to represent mg/L or mg/kg* It will be clear as ranges will be in the 0-20 ppm CO_2 (aq)**



C-sense Basics

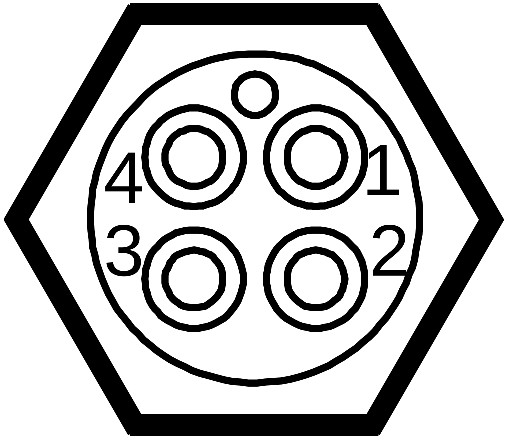
- Small pCO_2 sensor
- 3% Accuracy
- 0-5 V DC Analog Output
- 600m depth
- Ranges: 0-1000 ppm
  0-2000 ppm
  0-4000 ppm
  Others available

C-sense Set-up

- Simple setup for measurement
  - 6-12 V DC supply
  - Voltmeter / Multimeter

Pin Number	Function	Connection
1	Supply Voltage (6-12 VDC)	Positive Connection - PSU
2	Supply Ground (0 VDC)	Ground Connection - PSU
3	CO_2 Analog Signal Out “+” 0-5 VDC	Multimeter Positive Connection
4	Analog Ground “-“ 0 VDC	Multimeter Negative Connection

Back of C-sense



Male Impulse Connector
MCBH(WB)-4-MP-SS

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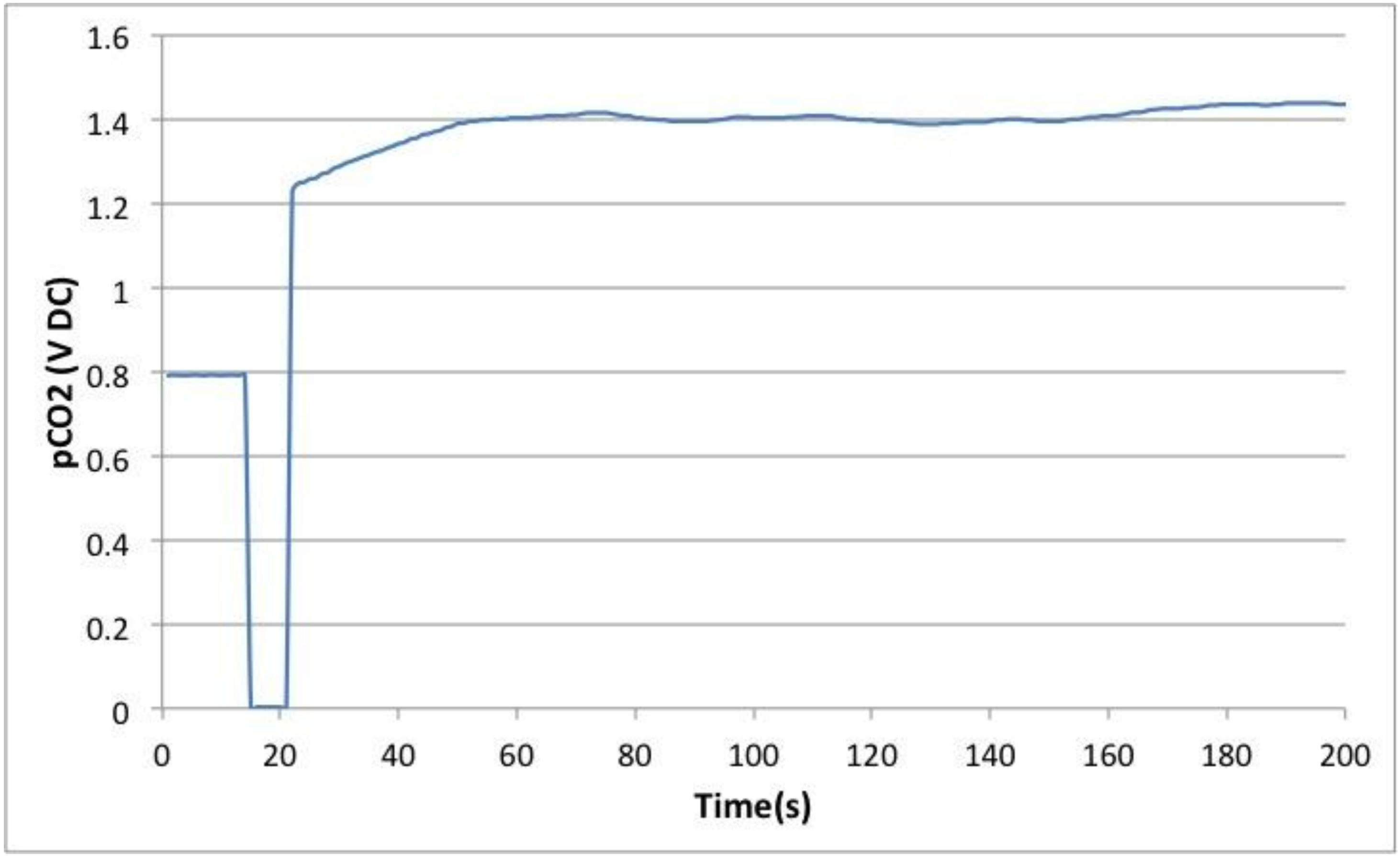
C-sense Initial Power Up

- Power can be applied when C-sense is in either air or water
- When power is supplied to the C-sense it will provide erroneous values for the first 20 seconds and then output values that trend towards the true measurement as the instrument warms up
- The detector cell outputs heat and provides a cell temperature that is 7-10 degrees Celsius higher than the surrounding water temperature – this takes a few minutes to thermally equilibrate

C-sense Initial Power Up



C-sense Deployment

- Can be placed in water in any orientation
  - User must ensure that NO gas bubbles are present on the membrane surface. Simple inversion of the C-sense when initially submerged followed by a gentle jiggle is sufficient
  - If positioned face up, ensure deposition of particles on the membrane is minimized – this will slow the response time
  - Horizontal or downward directions are best
- Water flow around the C-sense is preferred

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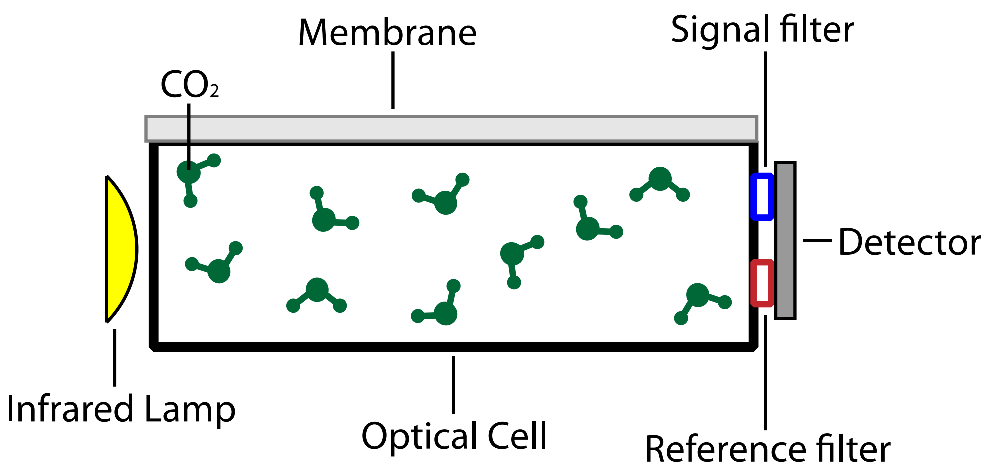
C-sense Method of Measurement

- Non-Dispersive Infrared (NDIR) detection
- **Measures pCO_2 (g) not CO_2 (aq)**
- Measures the absorbance of a filtered infrared wavelength by CO_2 molecules in a small gaseous headspace volume
- Detector measures a reference wavelength as well to compensate the measurement for ageing of the light source (dual wavelength)
- No interference from other gases, with the exception of water vapor, which has a small effect

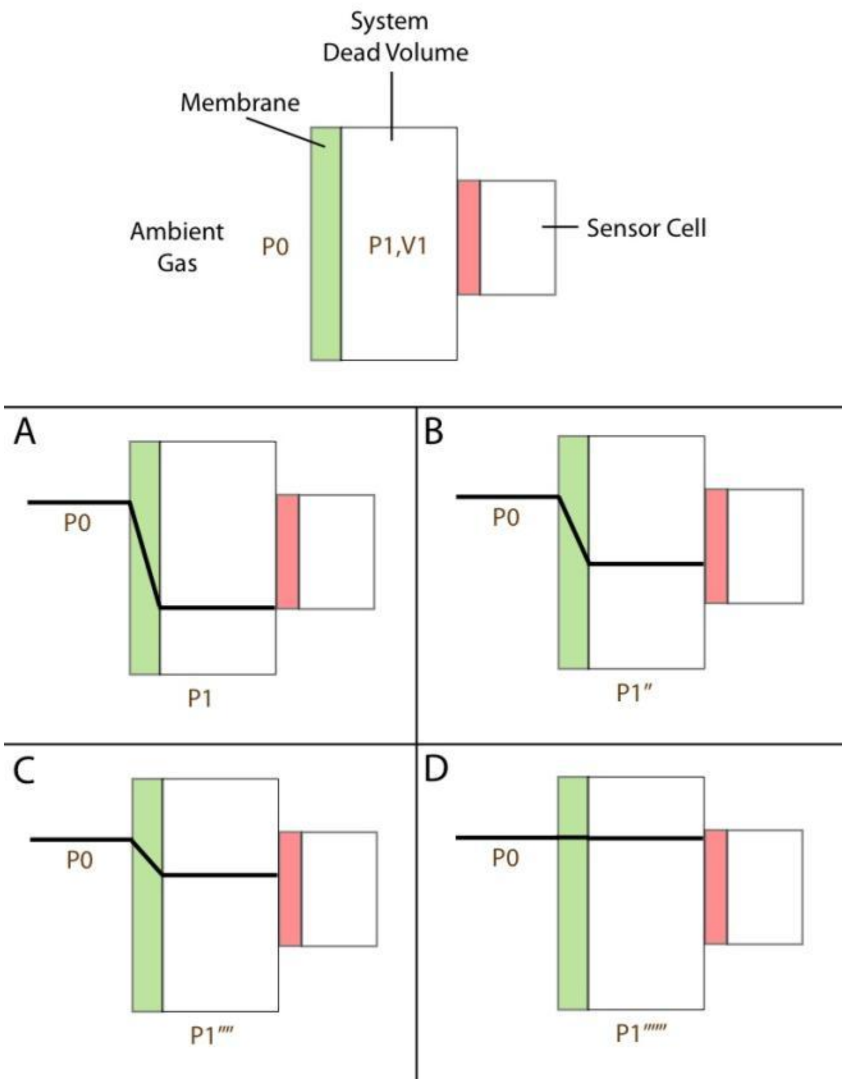


C-sense Method of Measurement

- Long-term drift is dependent on the number of hours the instrument is on
  - Light source ageing causes a slow change in the ratio of CO_2 to reference wavelengths
  - Typically 500-700 on hours for 1% drift
- Can be corrected for by measuring a reference gas and using the offset (linear across the scale)
- One method is to measure air at location before deployment and after to determine any drift for long deployments

C-sense Method of Measurement

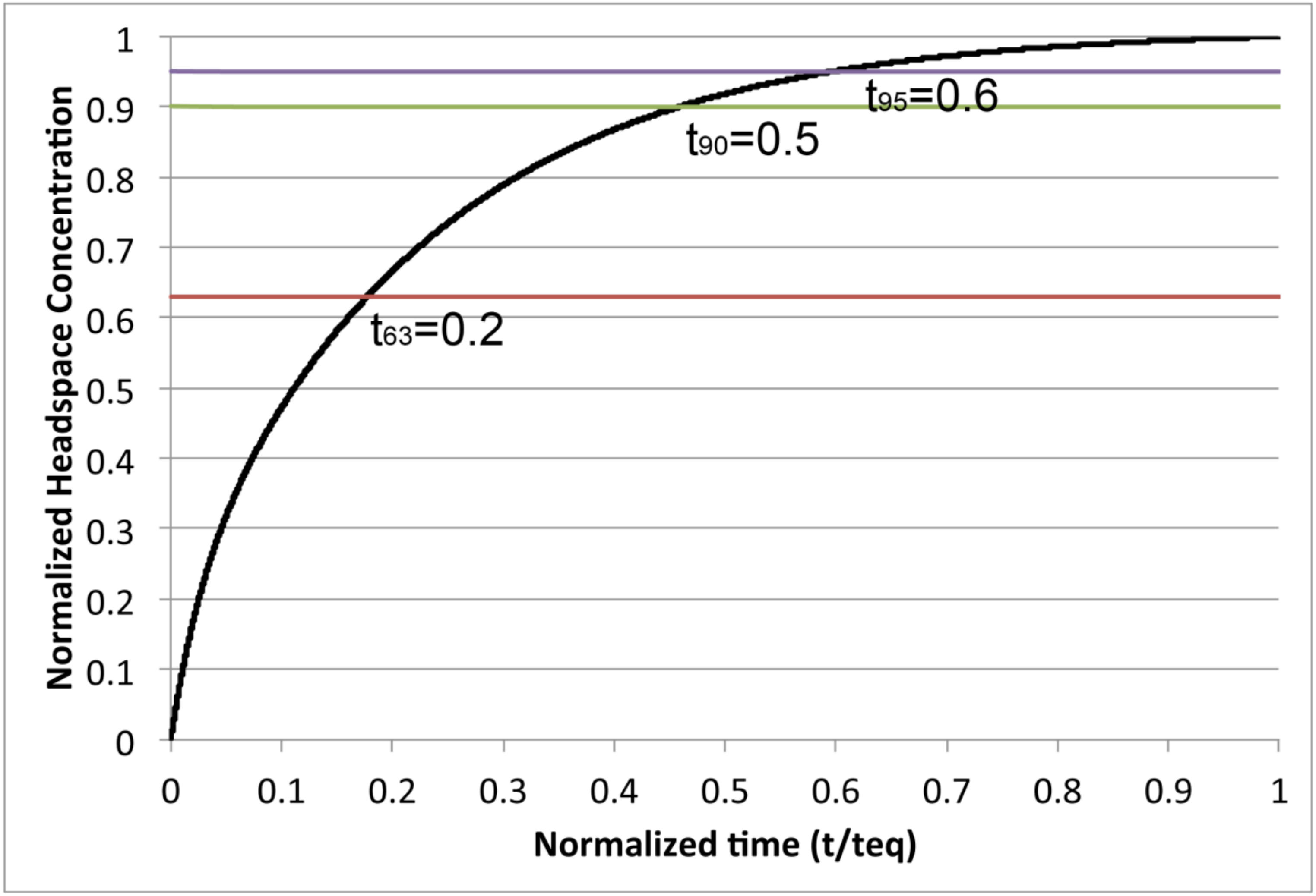
- Gas diffuses from water through a semi-permeable membrane into a gas headspace
- Membrane is supported to allow measurement under large hydrostatic pressure
- Membrane is extremely inert and does not suffer ill effects from most all contaminants potentially found in water



C-sense Semi-Permeable Membrane

- The only barrier between the water being measured and the detector
- Integrity of the membrane is key to proper functioning of the instrument
- Membrane should **not** be touched by fingers or other solid objects

C-sense Equilibration Time



C-sense in High TDGP Waters

- TDGP – Total Dissolved Gas Pressure
- Caution required in water where high supersaturation of waters with gases occur
- Build up of gas pressure on backside of membrane is okay provided there is sufficient hydrostatic pressure on the outside of the membrane to keep it from bulging
- Detector is not gas pressure compensated so deviations from atmospheric gas saturation will result in small error

C-sense Maintenance

- Requires minimal maintenance
  - Cleaning the membrane is all that is typically needed
  - Biofilms slow down the time to equilibrate and result in false readings due to either the consumption or production of CO_2 by biofilm organisms

C-sense Membrane Cleaning

- Do not touch the membrane at any time to avoid scratches and premature wear
- Use a dilute solution of High Efficiency laundry detergent in water, diluted 1:100 to 1:200
- Use a small submersible pump in the solution and direct the water flow directly onto the membrane face for 30 minutes. Place the pump 6 inches from the interface and direct water onto the instrument face
- Use clean water and the water pump for 15 minutes to fully rinse any soap residue from the membrane
- Air dry the membrane and place the protective cap over the end of the C-sense for storage

C-sense Biofouling

- Copper tape helps prevent biofouling
- Due to reactivity in seawater, copper must not contact SS head screws
- Copper tape should not be placed on the semi-permeable membrane
- 30 cut-outs included with each sensor

Place tape as shown

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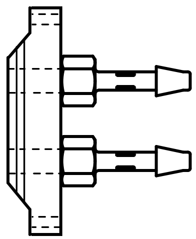
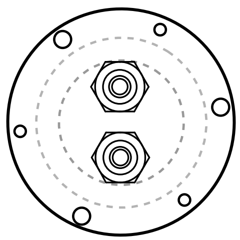
C-sense Water-Pumped Head

Water-Pumped Head Interface

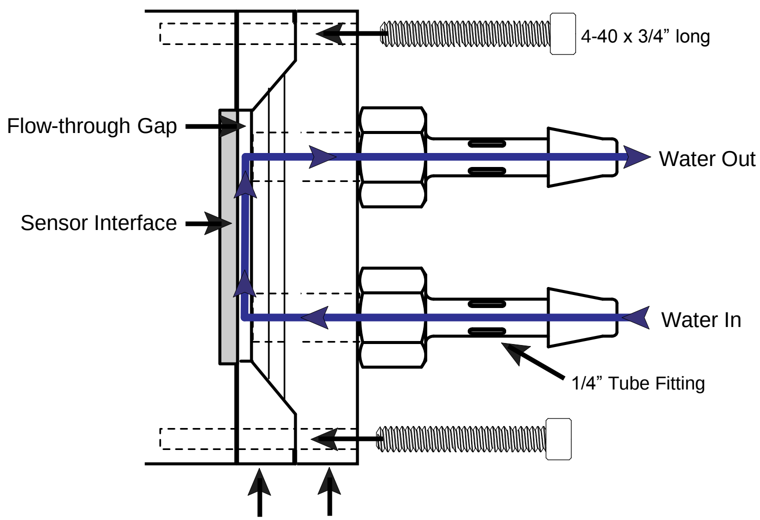


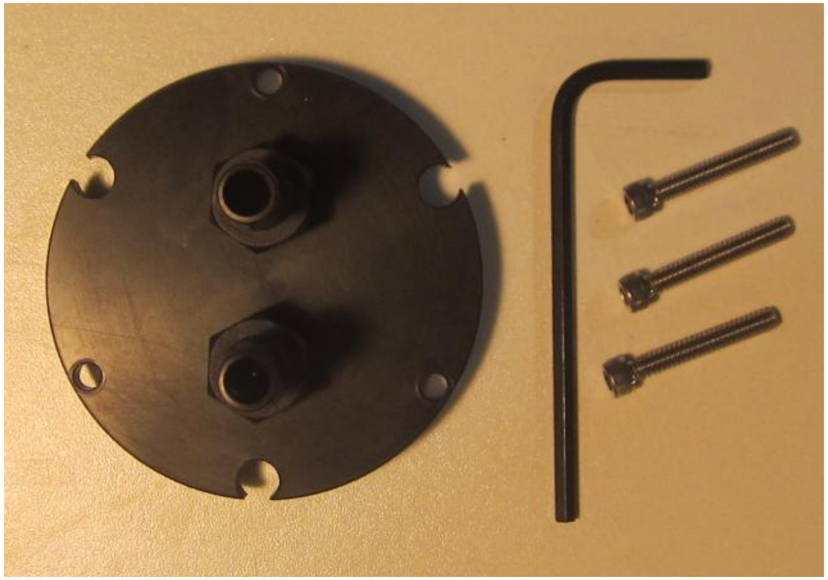
Side View



Face View

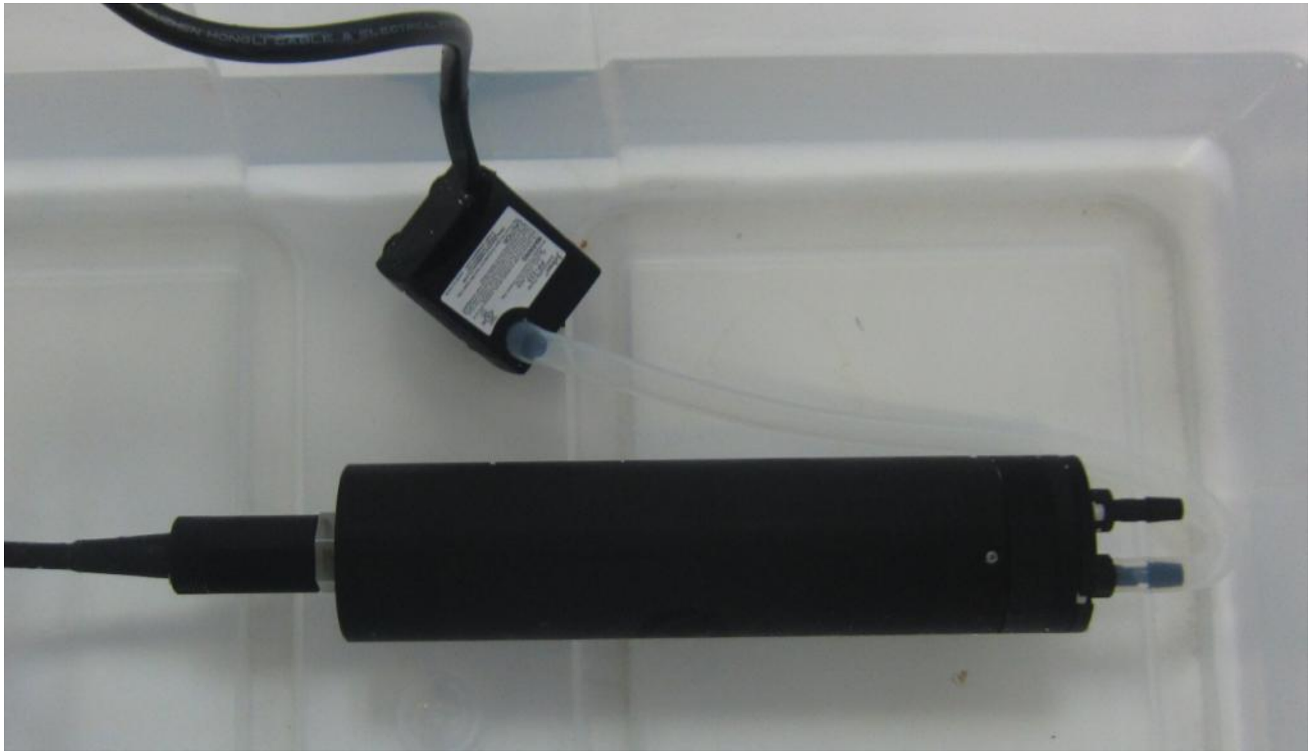
Installation and water flow diagram





- Pumped head comes with head, 3 screws for attachment, Hex key, and one foot of rubber tubing
- User responsible for supplying a water pump with a flow of 1-3 L/min (15-50 Gal/hr). Small submersible aquarium pump is sufficient for shallow/lab work, Seabird 5M pump or equivalent otherwise

Installed water-pumped head with small aquarium pump connected using tubing



Water inlet can be either port on the head assembly

Cleaning with the Water-Pumped Head

- Cleaning procedure similar to that without the attached pump head
- Use diluted soapy water, with pump attached as in the prior slide
- Clean water afterward to rinse using the water pump while still attached via tubing to head
- Remove tubing from head and connect a small air pump to one inlet of the head and pump air for 30 minutes through the head assembly to dry the membrane completely before storage

C-sense Troubleshooting

- No output voltage
  - Check power connections and ensure power supply is between 6 and 12 V DC
  - Check connector diagram to ensure C-sense is wired correctly
- Power connected improperly
  - Reverse polarity protected
  - Do NOT connect power to output pin

C-sense Troubleshooting

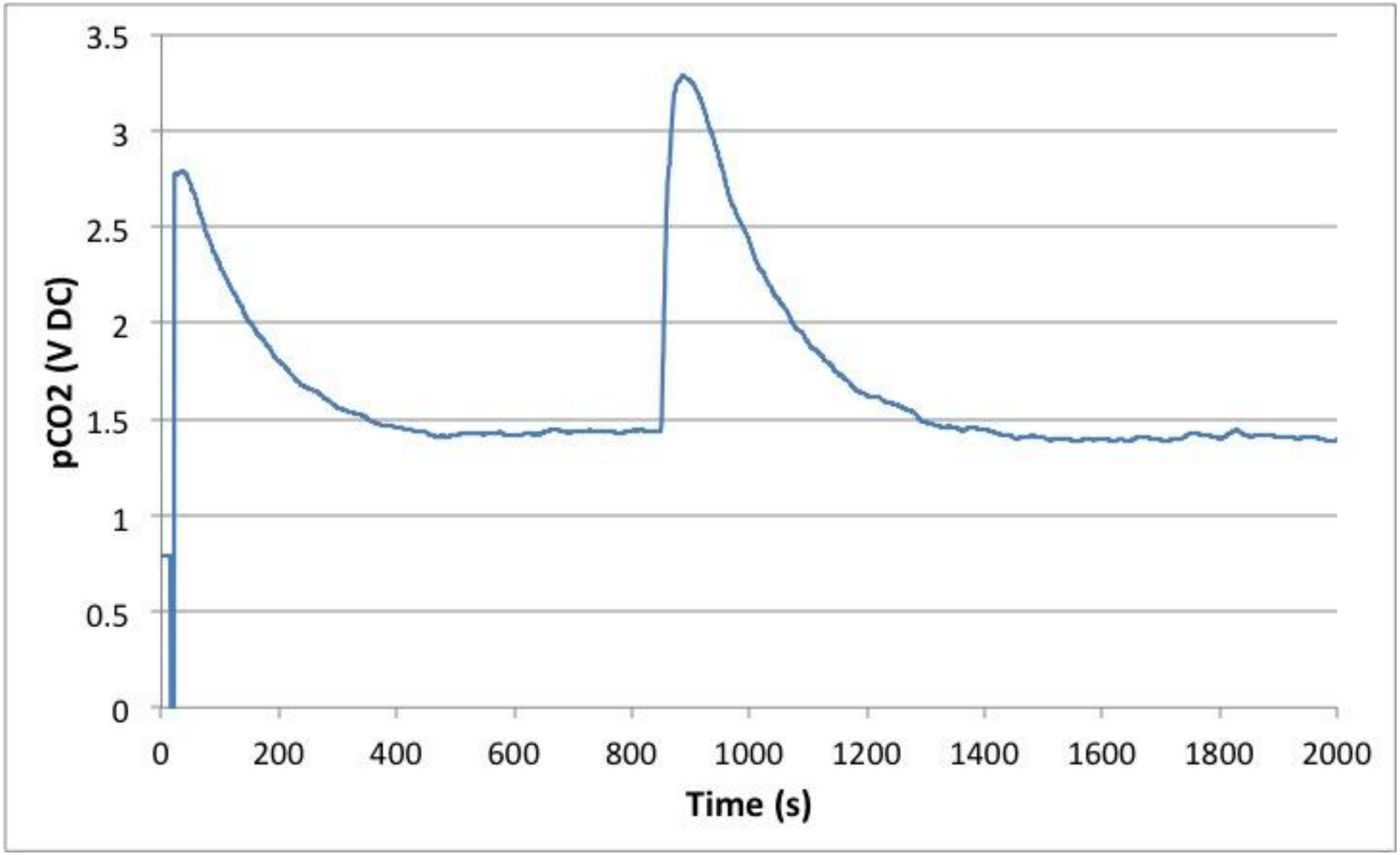
- Output reading remains at 0 V, 0.8 V or other voltage - Detector fault
  - Most probable cause is rapid change in conditions, typically temperature, wait for signal to return (5-15 seconds) – 0.8 V output
  - Water damage, check membrane for water underneath as well as possible location of puncture
- C-sense does not read 400 ppm in air
  - Common thought of many that the sensor will read 400 ppm in air, FALSE
  - Most typically around 450 ppm outside and anywhere from 500-1500 ppm in buildings / labs

C-sense Troubleshooting

- During lab testing (in air) C-sense reads too high or shows large fluctuations
  - Human breath contains ~40,000-50,000 ppm CO_2, ensure sensor head is pointed away from human exhalation
- Equilibration time is really slow
  - Biofilm or other foreign substance on the membrane – clean using the cleaning procedure in the manual

Effect of Human Breath

Result of 3 seconds of exhalation directed toward membrane



Applications of pCO_2 Sensors

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pCO_2 Applications

- Water quality monitoring
- Ocean acidification
- Carbon fluxes
- Photosynthetic/ respiration rates
- Aquaculture health
- Algae growth
- Wastewater monitoring
- Carbon capture and storage monitoring

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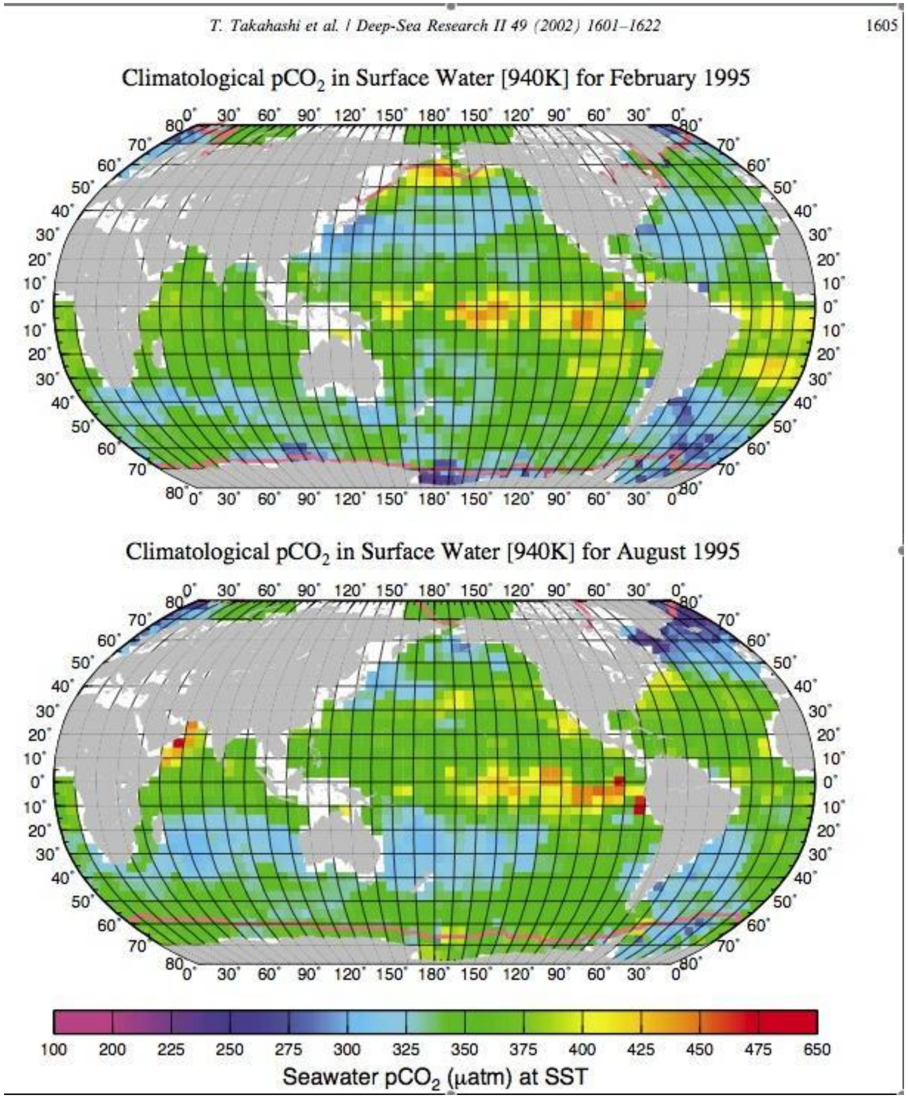
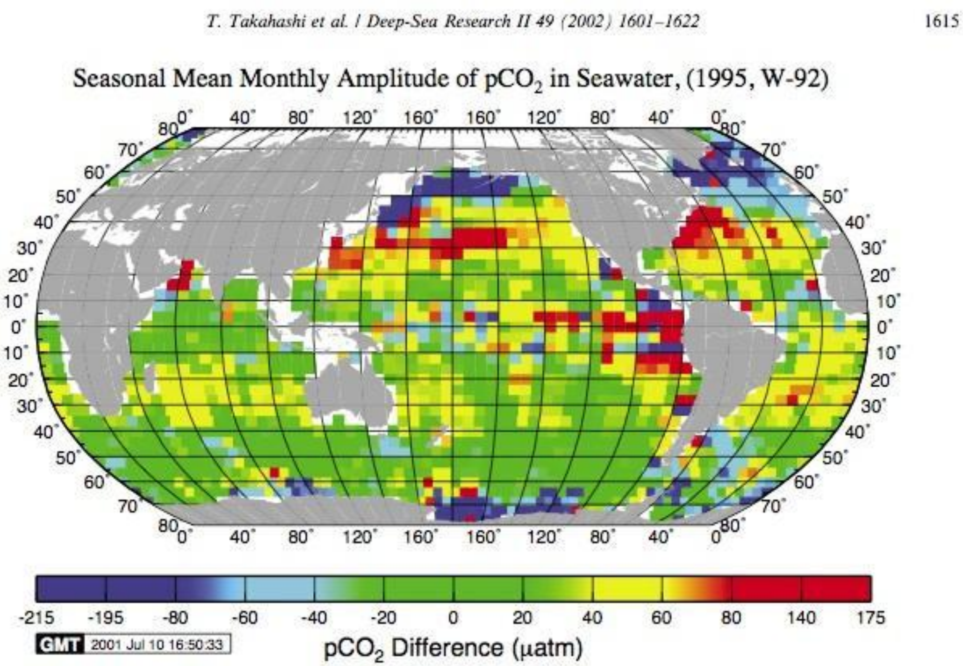
pCO_2 Applications

- Given the broad range of applications the customer base is just as varied
  - Government vs Industry vs Academic
- Standard practice differs across fields
  - How and what is measured
  - How it is reported, measurement units for example
- Expected pCO_2 values can range from 0-10,000 ppm and even as much as 0-100% (1,000,000 ppm)

Applications - Open Ocean



- Surface ocean has small range of pCO_2 (<1000 ppm)
- Good interaction with the atmosphere
- Seasonal changes are highly variable

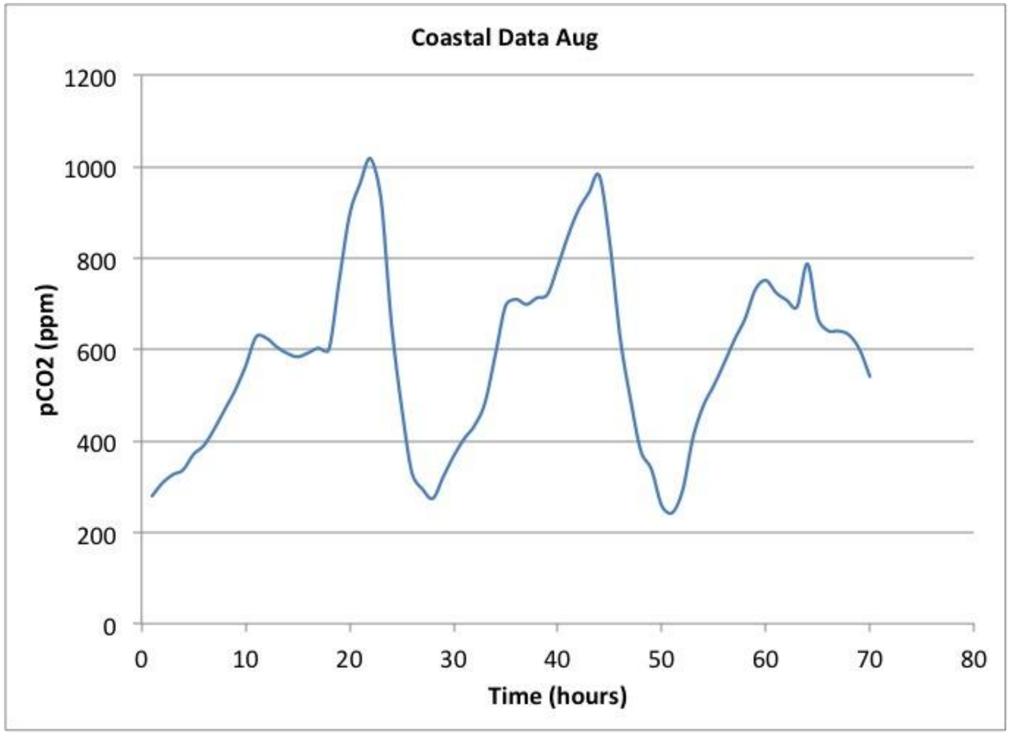


Applications - Open Ocean

- With increasing depth in the ocean, pCO_2 tends to increase
  - Water is isolated from the atmosphere
  - Lack of photosynthesis combined with respiration leads to buildup of CO_2 in deep ocean
  - Levels as high as 1000-1500 ppm are common in bottom waters of deep ocean

Applications - Coastal Waters

- Highly dynamic areas – results in large variability both spatially and temporally
- Very often short-term, large-scale changes occurring



Applications - Rivers

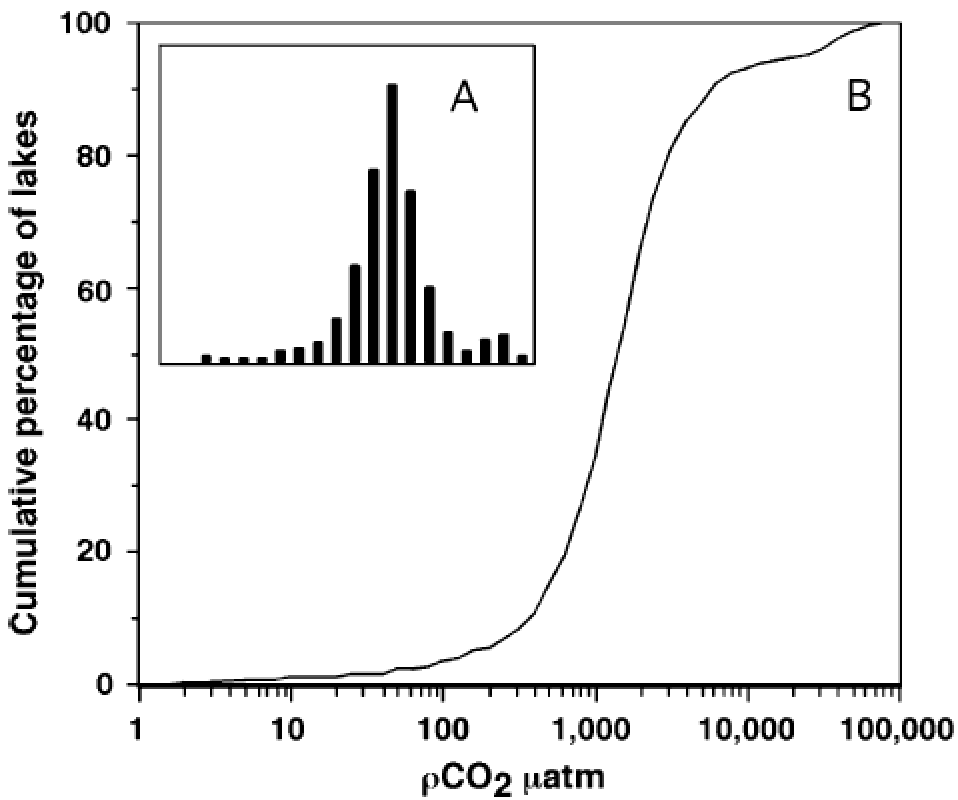
- pCO_2 can be highly variable over seasonal time scales
- Ranges commonly seen range from 100-2000 ppm
- Some rivers have much higher levels
- Organics in the water column dictate pCO_2 in most river instances
- Carbonate rock dissolution is also a factor

Applications - Estuaries

- pCO_2 ranges typically from 500-4000 ppm
- Ocean end lowest pCO_2
- River end highest pCO_2
- Numerous inputs from humans, respiration of organisms, and interactions with bottom sediments

Applications - Lakes

- Commonly supersaturated with CO_2
- Example of 948 Florida Lakes
- Many lakes fall in the 0-2000 ppm range
- Worldwide estimates and averages are similar in nature to Florida example
- High DOC inputs and respiration key factors



Lazzarino et al 2009

Applications – Aquaculture Finfish

http://www.dfo-mpo.gc.ca/aquaculture/rd2007/rdsalmon-saumon_06-eng.htm

- High CO_2 levels in finfish has been linked to
  - Poor growth and development
  - Poor ion regulation
  - Nephrocalcinosis

- CO_2 Levels should be kept below 2000 ppm, optimal is much lower, 500-1000 ppm for most all fish
- Both open water and tank should be monitored

http://www.sardi.sa.gov.au/aquaculture/aquatic_sciences/sa_aquatic_sciences_centre/pool_farm

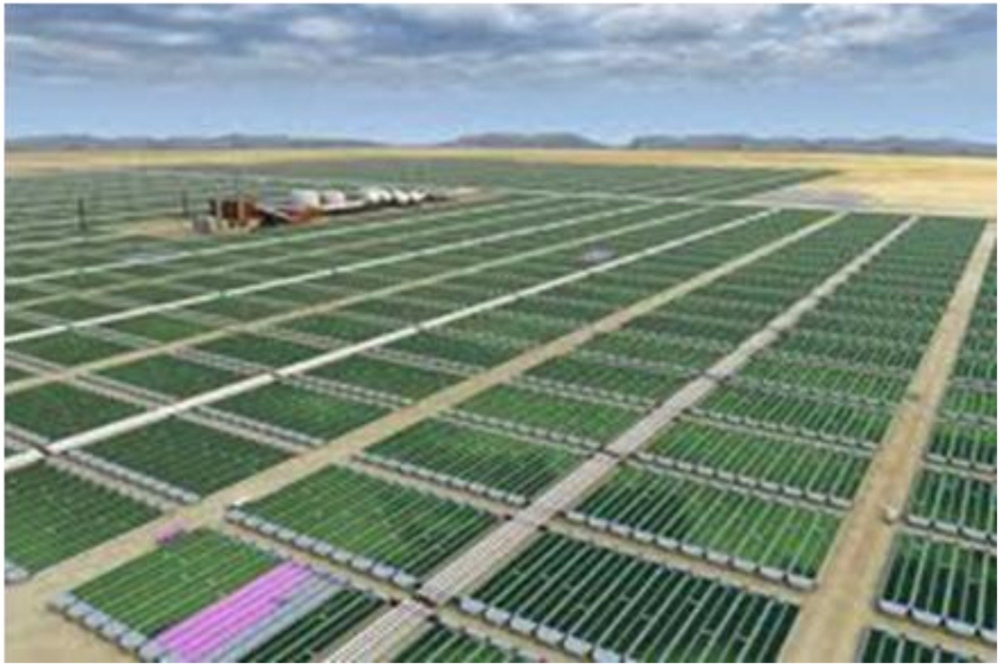
Applications – Aquaculture Shellfish

- High levels of CO_2 in water will inhibit the precipitation of calcium carbonate (CaCO3) shells
- Oysters, scallops, and clams are very sensitive to increases in pCO_2

https://www.whoi.edu/seagrant/page.do?pid=51817&tid=282&cid=88727

Applications - Algae growth

- Production of algae for fuel, pharmaceuticals and nutraceuticals
- Pilot-scale testing needs pCO_2 measurement for determining optimal levels for growth



- Large-scale production requires regulating CO_2 as waste through loss to atmosphere is costly
- Need to balance optimal growth pCO_2 level with cost of CO_2 in many cases

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Applications - Wastewater Monitoring

- High organic loading results in rapid decay and production of CO_2 byproduct
- Carbon tax in some countries requires monitoring of wastewater CO_2 for credits during CO_2 reduction processes
- Levels can be upwards of 10,000 ppm in some holding ponds

Applications - CCS Monitoring

- Carbon capture storage (CCS) pump large amounts of CO_2 at great depths in saline aquifers
- Monitoring to ensure CO_2 remains at depth
  - Aquifers
  - Groundwater
  - Surface waters
- Range of CO_2 dependent on location, greater depth of measurement expect higher CO_2
- In the saline aquifers, CO_2 reaches 10% or more