TWLWG 09 Canadian Presentation
(Atlantic Perspective on tidal science and data collection)

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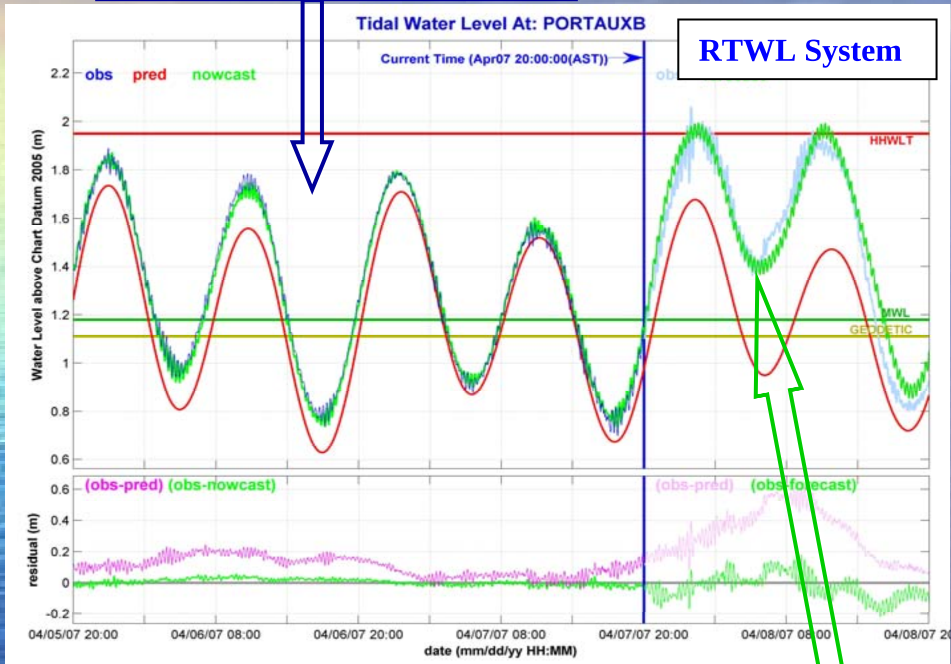
Canadian Hydrographic Service Atlantic

PWLN

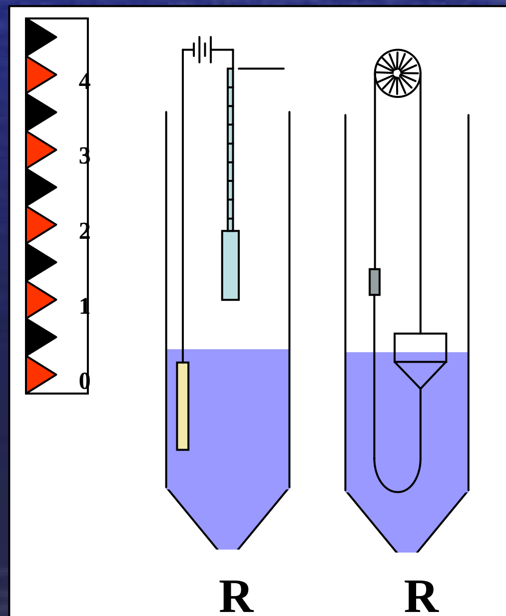
observe, collect, predict

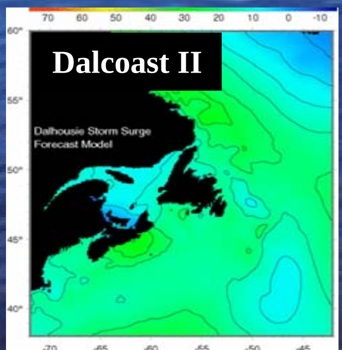
RTWL System



Water level measurement systems/sensors

data quality is only as good as data collection system





+

$$s_t = (I - KH)Ms_{t-1} + Kx_t$$

$$K = \kappa[1\ 2\ 0\ 2\ 0]^T$$

$$H = [1\ 1\ 0\ 1\ 0]$$

$$\langle x_t \rangle = Hs_t$$

forecast

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & \cos(\omega_1) & -\sin(\omega_1) & 0 & 0 \\ 0 & \sin(\omega_1) & \cos(\omega_1) & 0 & 0 \\ 0 & 0 & 0 & \cos(\omega_2) & -\sin(\omega_2) \\ 0 & 0 & 0 & \sin(\omega_2) & \cos(\omega_2) \end{bmatrix}$$

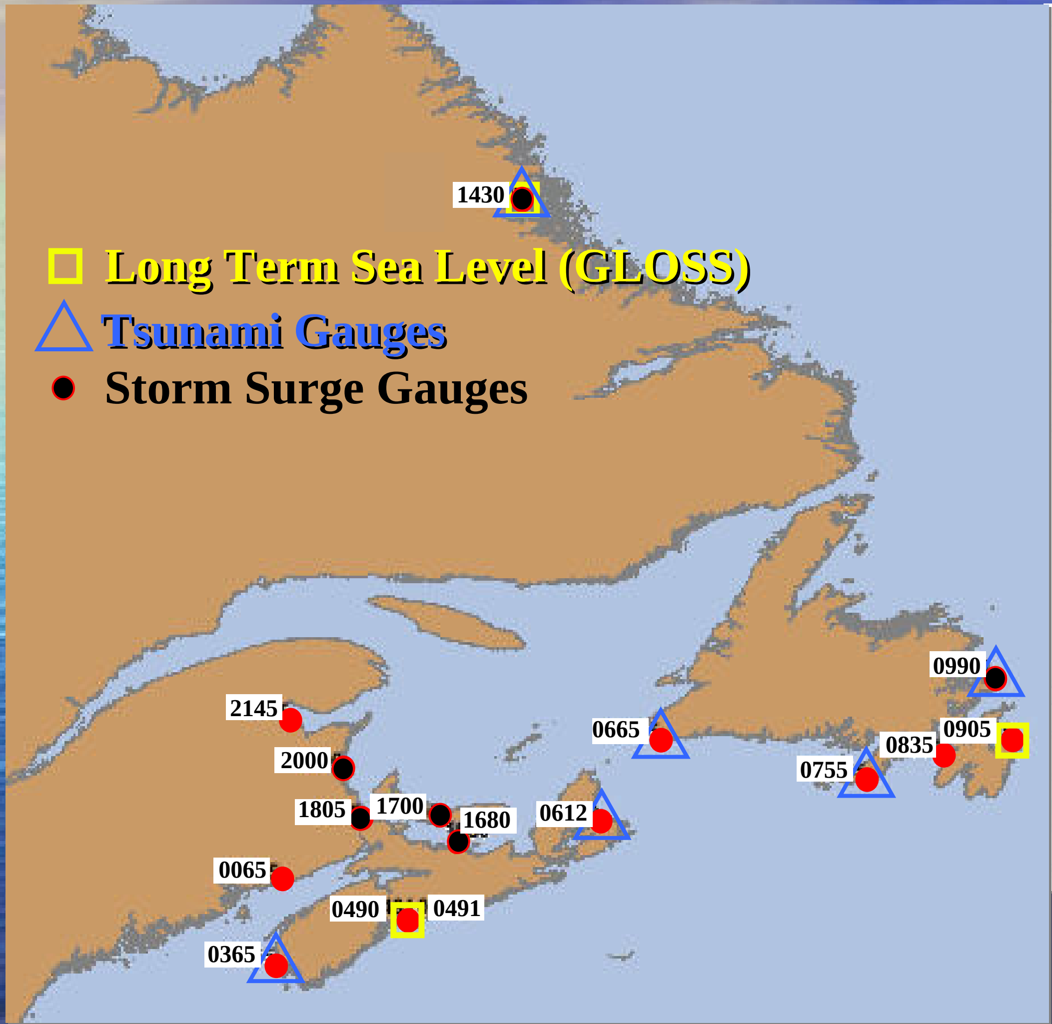
zero phase shift, multi band pass, recursive filter

CHS Tidal Responsibilities

- Maintain/develop Canada's PWLNs
- Collect PWLN and hydrographic field water level and current data
- Provide water level data (obs,pred,modeled, …) for field survey sounding reduction
- Establish and track point centric hydrographic vertical datums and develop vertical transform surfaces
- Provide field document vertical control information (datums and transforms)
- Operational oceanography (tsunami, storm surge, flooding)

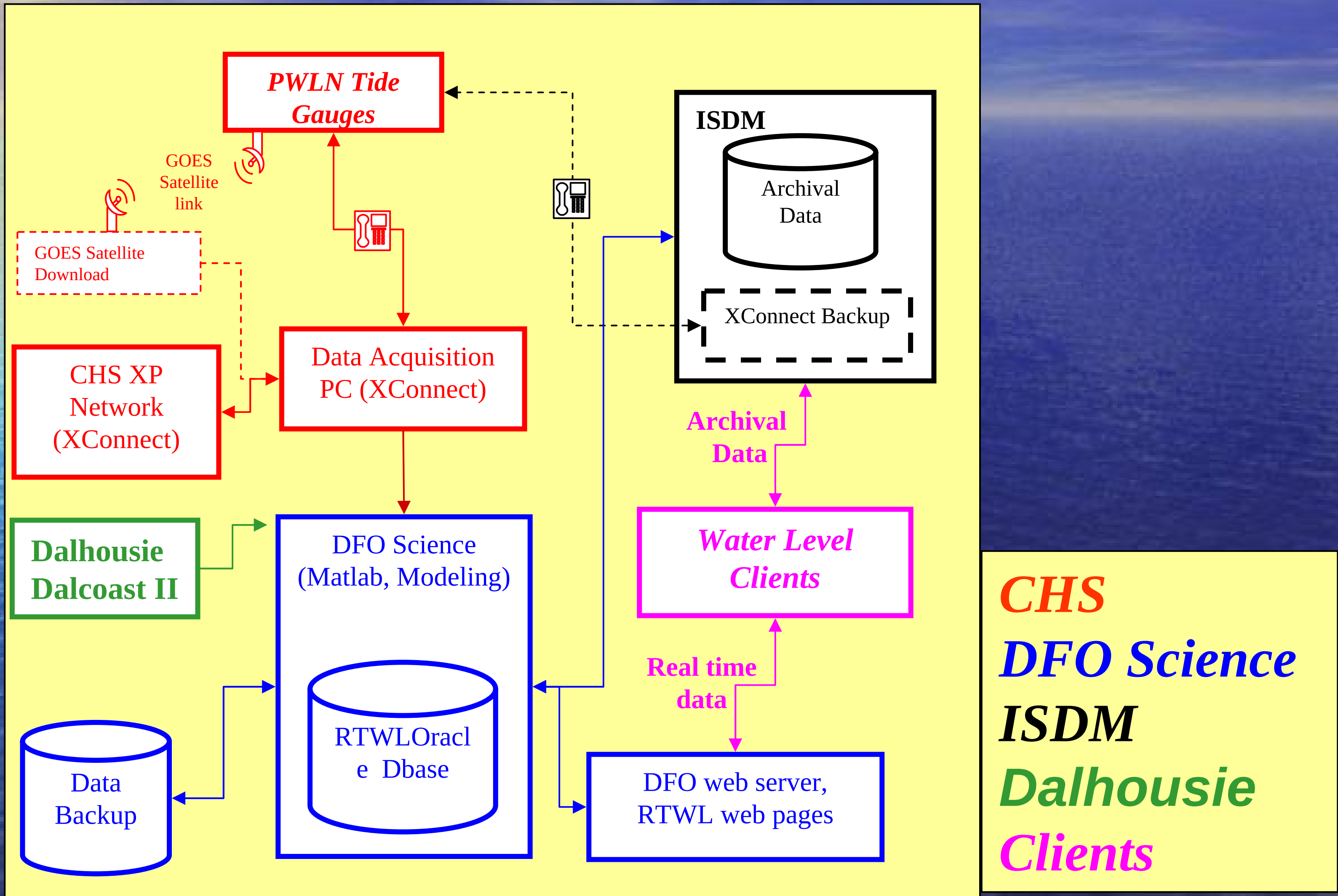
Atlantic's Permanent Water Level Network

16 tide gauges, 000's kms of coastline

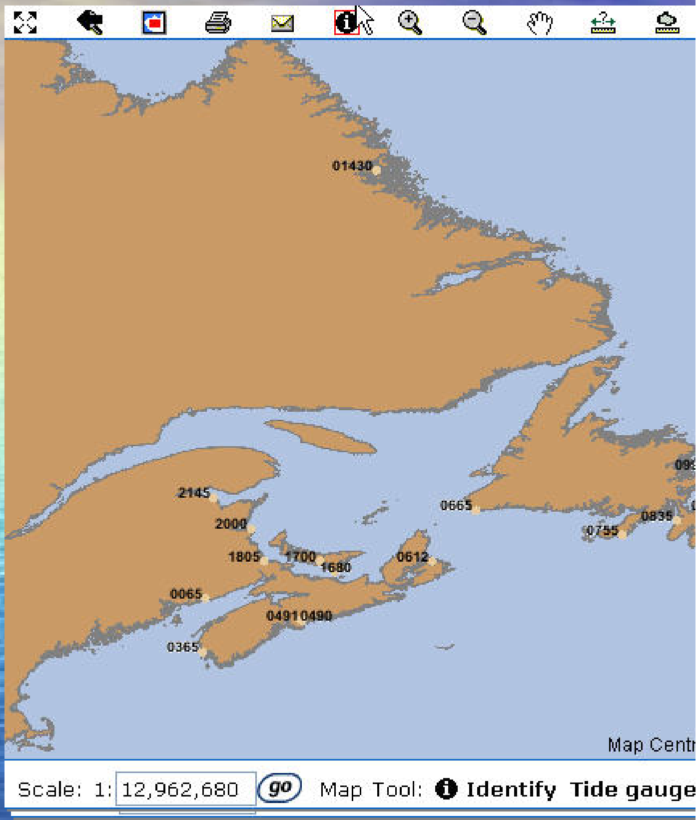


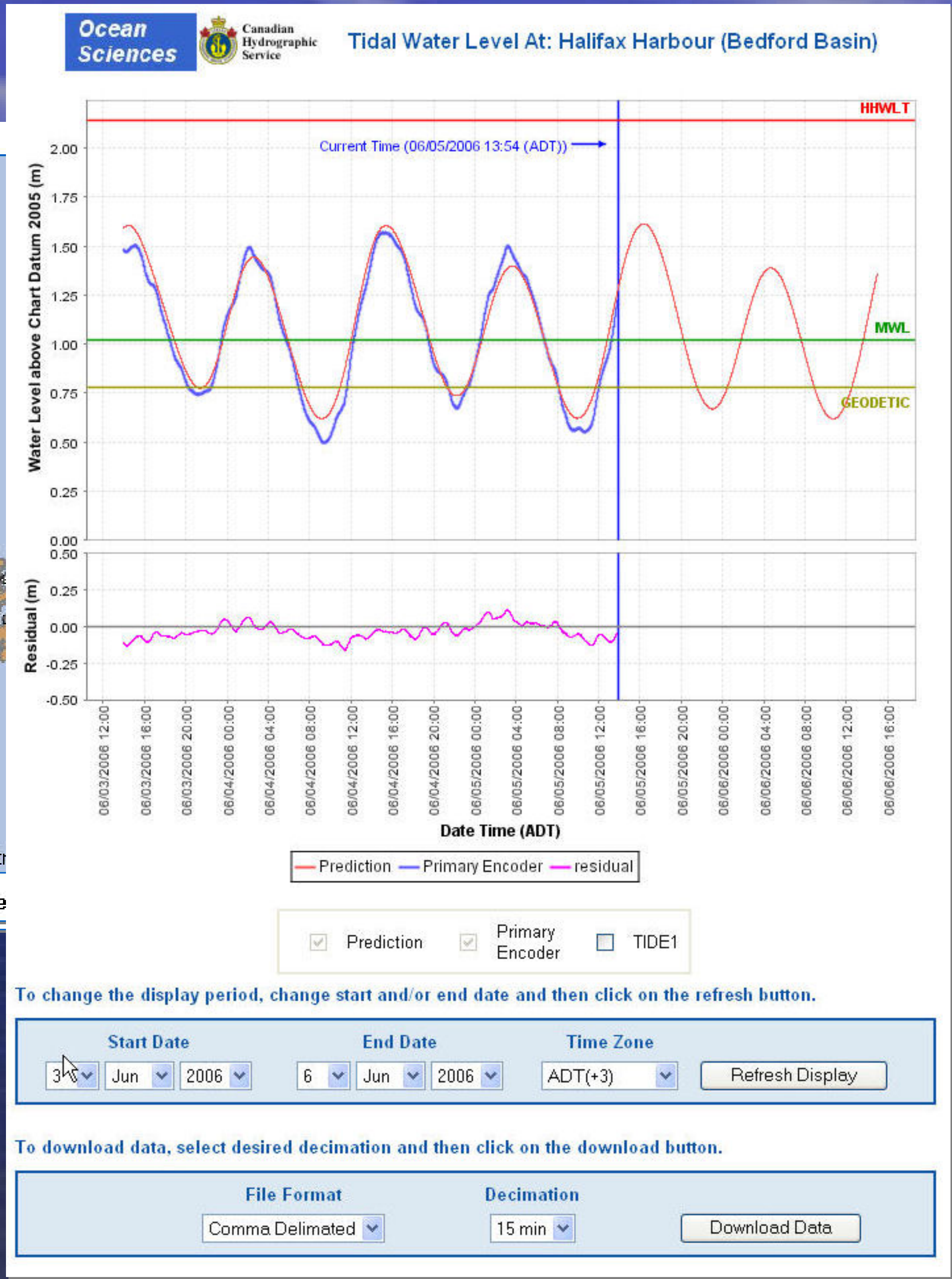
0065 Saint John
0365 Yarmouth △
0490 Halifax □
0491 Dartmouth, BIO
0612 North Sydney △
0665 Port aux Basque △
0835 Argentia
0905 St. John's □
1430 Nain □ △ ●
1680 Wood Islands ●
1700 Charlottetown ●
1805 Shediac ●
2000 Escuminac ●
2145 Belledune
0755 St. Lawrence △
0990 Bonavista △ ●

Atlantic RTWL System



Atlantic RTWL Web Pages





Forecasting the Residual

- *Effects of weather*

  Dalcoast II -- 2D, barotropic, non-linear, lateral diffusion, 1/12°, forced by EC 3hr winds and pressure (48hr surge forecast, once per day)

- *Everything else*

  Spectral-nudging Kalman Filter (Thompson etal., 2006)

  -- zero phase shift, multi band pass, recursive filter

$x_1, x_2, \ldots, x_t$ equispaced scalar values to be filtered

s_t denote an auxiliary state vector

Build Term **Decay Term**

$$s_t = (I - KH)Ms_{t-1} + Kx_t$$

Nowcast

$$K = \kappa_t[1 \quad 2f_1(\omega_1) \quad 0 \quad 2f_2(\omega_2) \quad 0]^T$$

Filter band pass width, gain, (spin up period)$^{-1}$

$$H = [1\ 1\ 0\ 1\ 0]$$

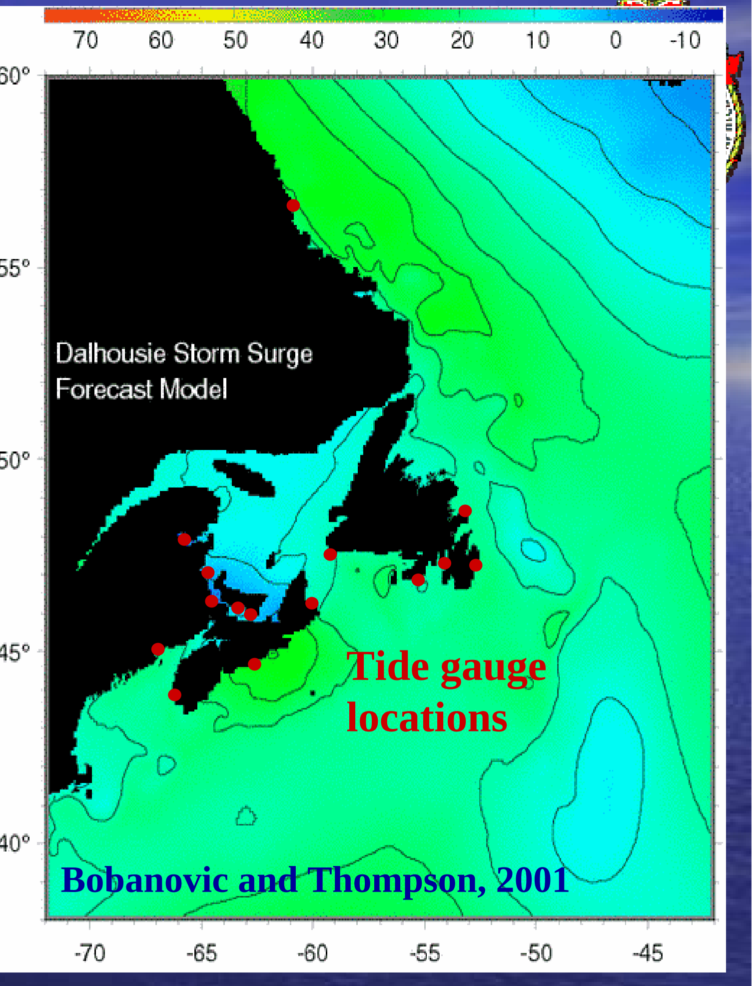
Bias term →

Band Pass Frequencies

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & \cos(\omega_1) & -\sin(\omega_1) & 0 & 0 \\ 0 & \sin(\omega_1) & \cos(\omega_1) & 0 & 0 \\ 0 & 0 & 0 & \cos(\omega_2) & -\sin(\omega_2) \\ 0 & 0 & 0 & \sin(\omega_2) & \cos(\omega_2) \end{bmatrix}$$

Filtered values $\langle x_t \rangle = Hs_t$

Forecast $s_t = Ms_{t-1}$

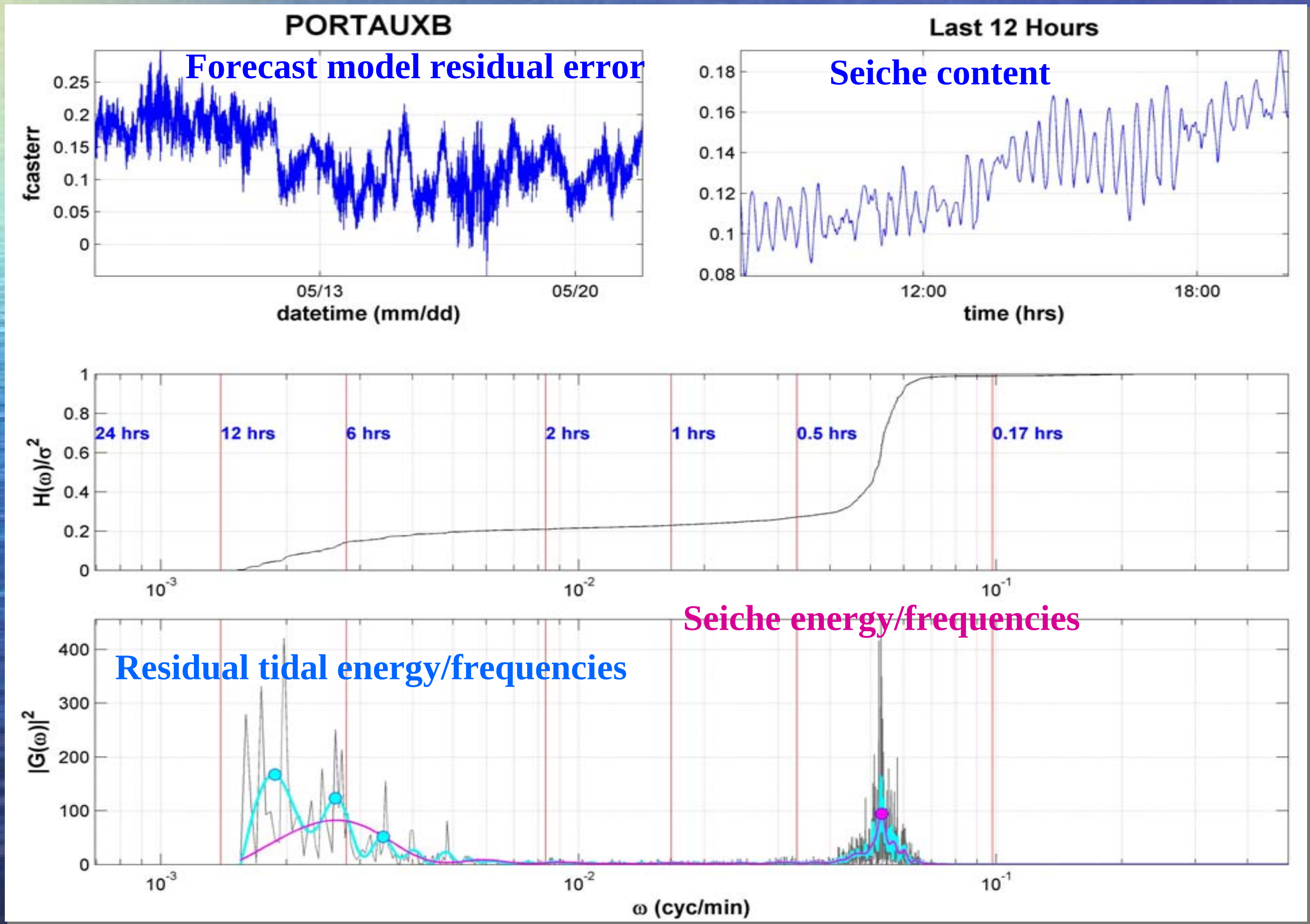


Proto-Forecast = **Constituent Predictions + timeseries of 0-24 hr surge + 24-48 hr surge**
Forecast model residual error = **Observations (up to last) – (Proto-Forecast)**
Residual error Nowcast = **Filter (forecast model residual error),** ***Nowcast mode, build/modify state vector energy**
Residual error forecast = **Filter,** ***Forecast mode, project existing state vector energy into the future (no decay)**
Final forecast = **Proto-forecast + residual error nowcast and forecast**

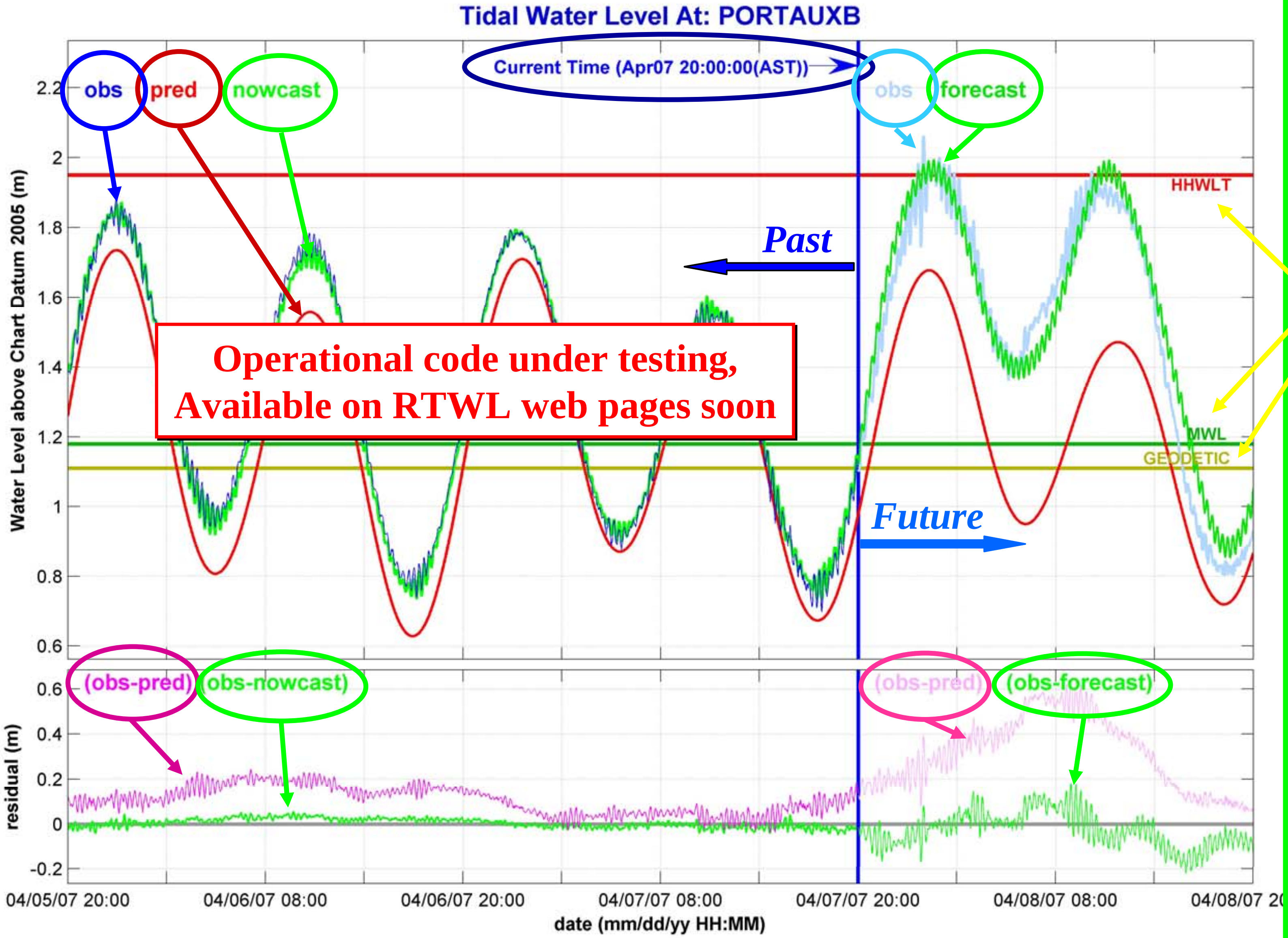
Selection of Filter Frequencies and Gains

- ***From Theory:*** **Diurnal O_1, Semidiurnal M_2**
  gain/filter band widths wide enough to capture other diurnal and semidiurnals
- ***From Recent Observations (analysis of forecast model residual error timeseries):***

Upper Tidal and Seiche Frequencies, gain/decay timescales ~ 1.5 to 2 wave periods



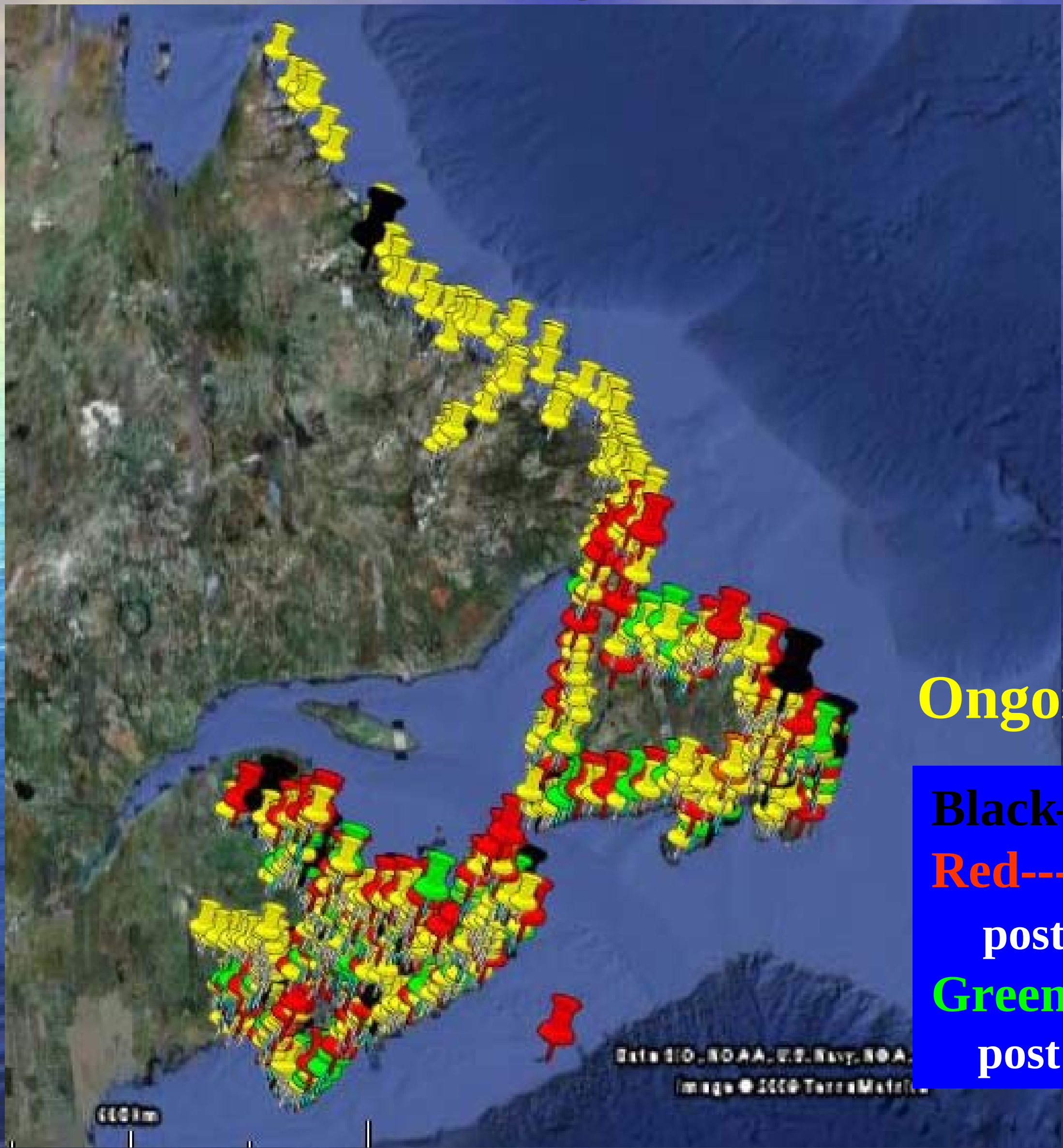
Example Forecast



Operational code under testing, Available on RTWL web pages soon

Vertical Control and Transforms

Legacy Station-Centric



Ongoing vertical control project

Black—PWLN Stns

Red---Re-occupy 24 hr

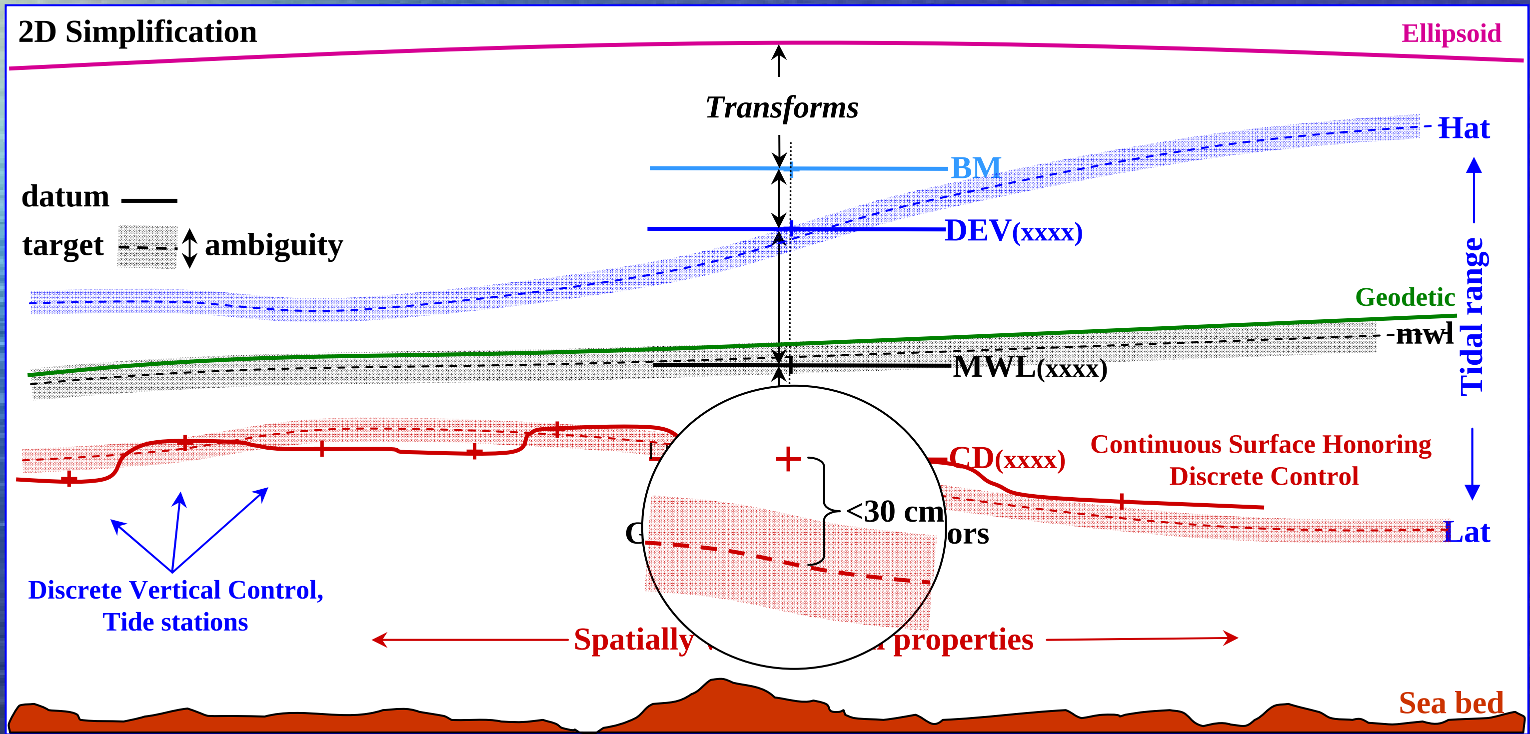
post processing, long baseline +/-1cm

Green---Re-occupy <24 hr

post processing secondary stns, +/-3 cm

Long Timescale WL Monitoring
Vertical Control Datum Management

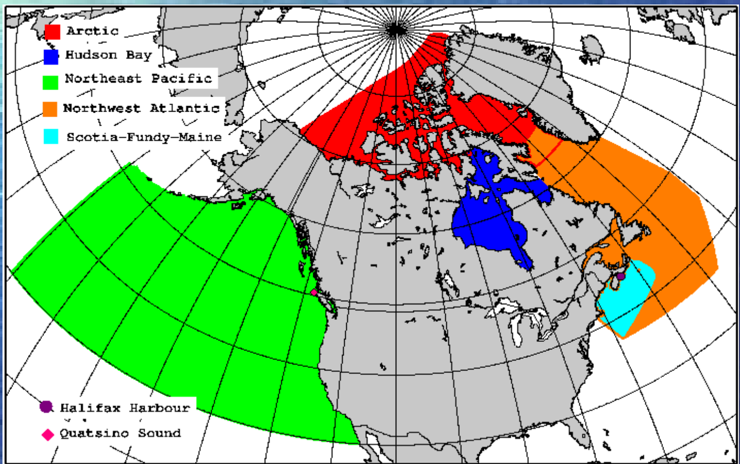
- **Hydrographic reason to maintain a minimal, effective water level monitoring network/program,** *maintain/track tidal datums wrt relative sea level rise*
- **Past approach**
  Constant Datum Transform Assumption (CDTA)



Continuous Datums and Transforms

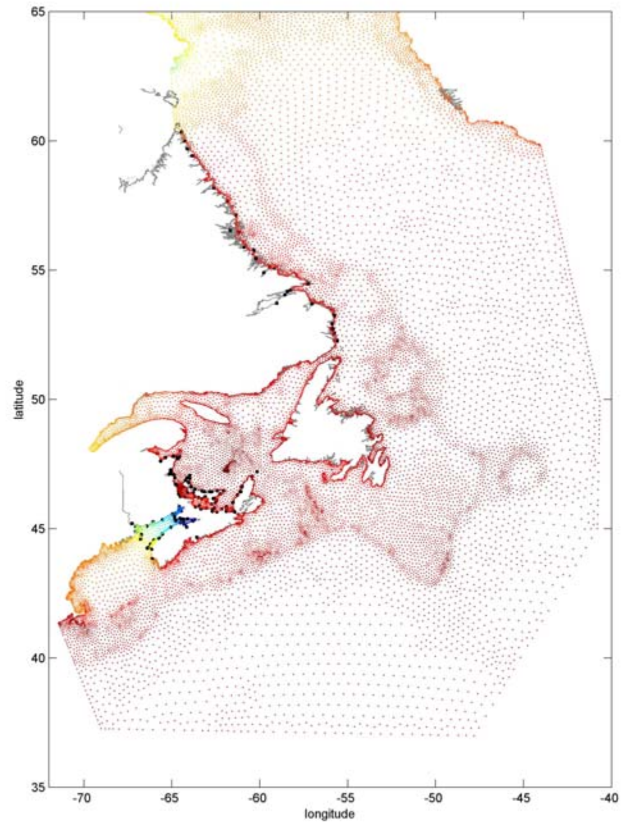
Why do we need them?

- With GPS based vertical positioning, RTK or modeled (Omnistar), errors introduced to charts by the CDTA can become significant part of vertical error.
- CDTA can be inappropriate some activities:
  - route surveys
  - surveys where tidal target surfaces change significantly over survey scale (estuaries, Bay of Fundy)
  - Flood mapping of large areas
  - RTK solutions and Anywhere, anytime water level applications (WebTide), Continuous applications need continuous datums



WebTide

Multi-constituent, anywhere tidal prediction

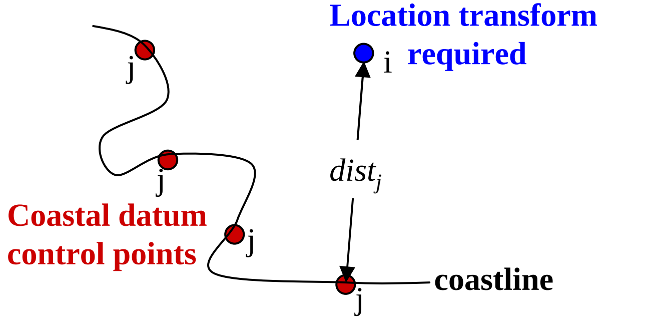


Constituents derived from a Hydrodynamic Barotropic Ocean Model Assimilating Topex Posieden Altimeter data

Dupont, F., C.G. Hannah, D.A. Greenberg, J.Y. Cherniawsky and C.E. Naimie. 2002. Modelling system for tides for the North-west Atlantic coastal ocean. [online]. [Accessed 21 April, 2008]. Available from World Wide Web: http://www.dfo-mpo.gc.ca/Library/265855.pdf

Distance weighted datum transform
MWL to CD (Discrete calculation)

Webtide provides anytime, anywhere tidal prediction wrt to a floating MWL
We want tidal prediction wrt CD, need anywhere transform between MWL and CD



$$T_i = \sum t_j w_j, \quad \sum w_j = 1$$

$$w_j = \frac{(far - dist_j)^p}{\sum_j (far - dist_j)^p}$$

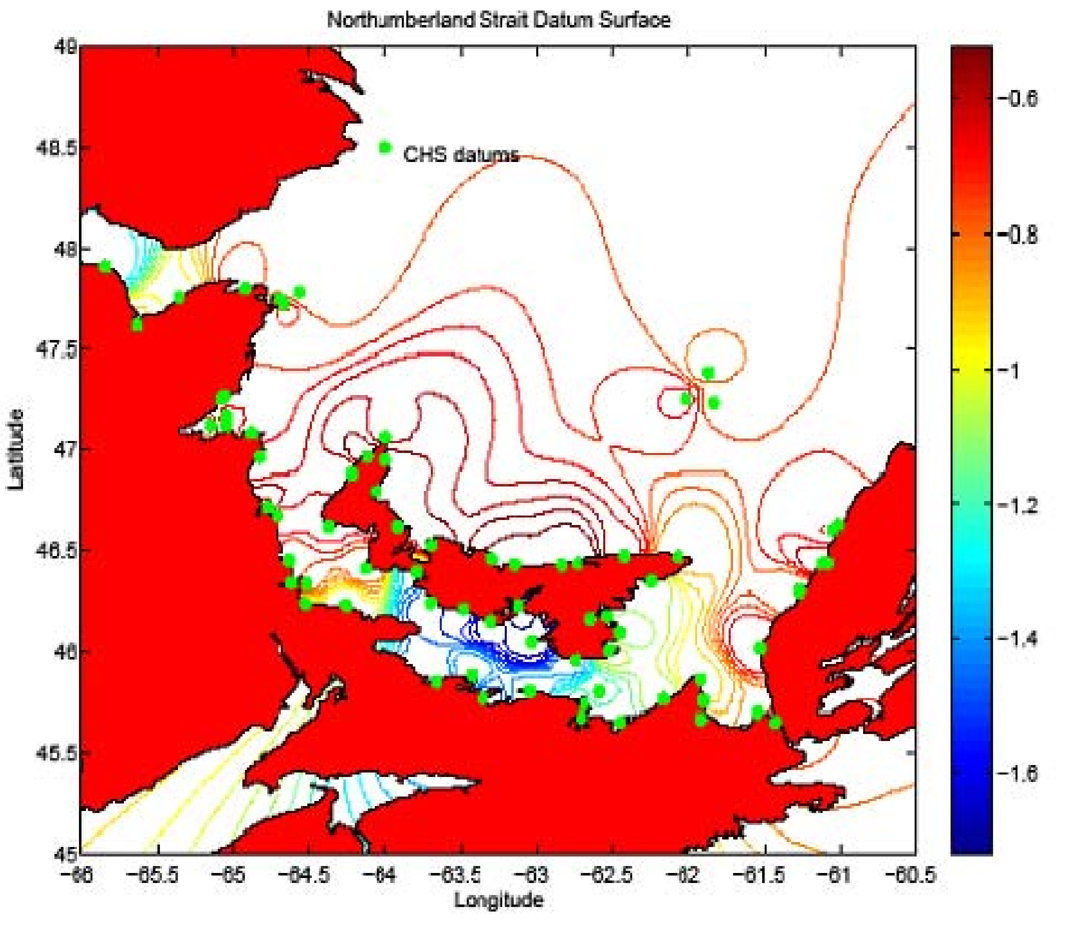
T_i – transform at i
t_j – transform at j
w_j – weight for t_j

far=max($dist_j$)

Exponent p determines local flatness and width of transition zone

Used in:

- **Labrador 06-07**
- **Northumberland 07**
- **Fundy 07**

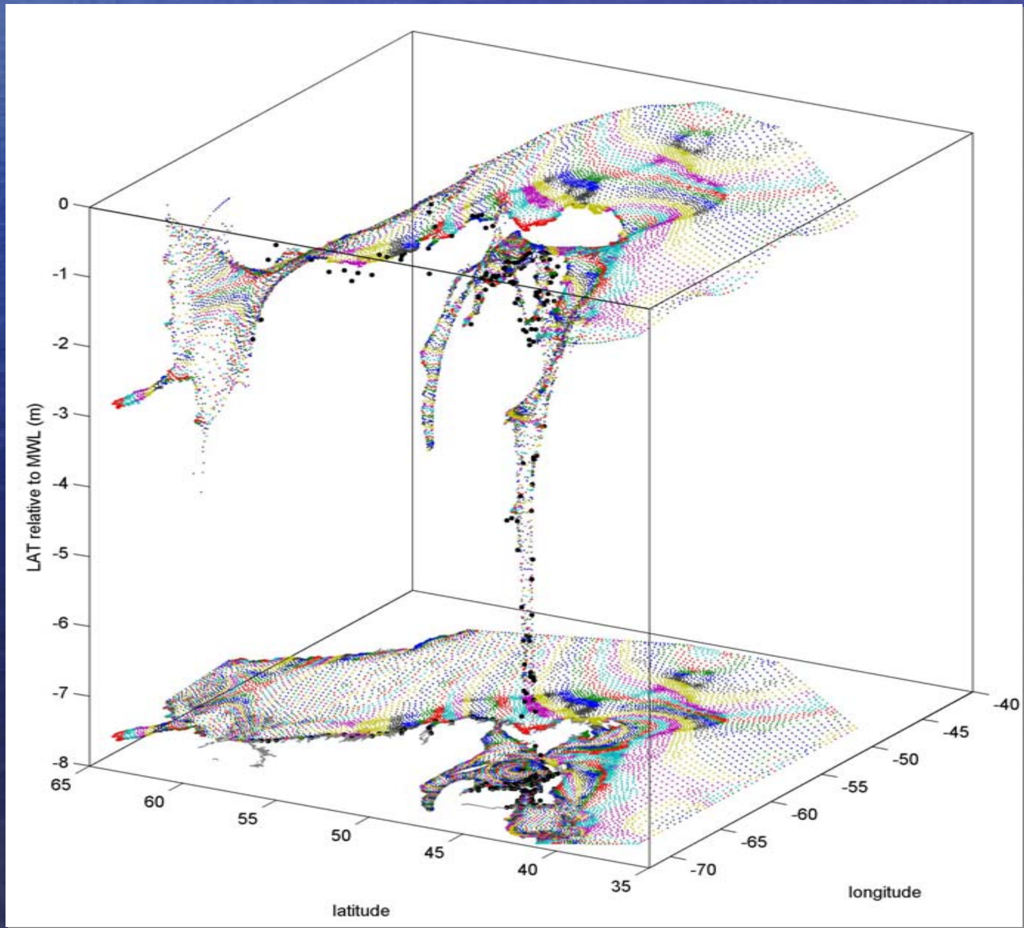


Need Consistent Well Considered Approach

- *Closely examine the programs and methods employed by others, NOAA/NOS, UK*
- *Discuss options with Datum clients*
- *Develop project outlines/proposals*
- *Acquire necessary resources and get on with it*

Example: Atlantic Canada MWL_LAT Transform

LAT as Sum of WebTide constituent amplitudes

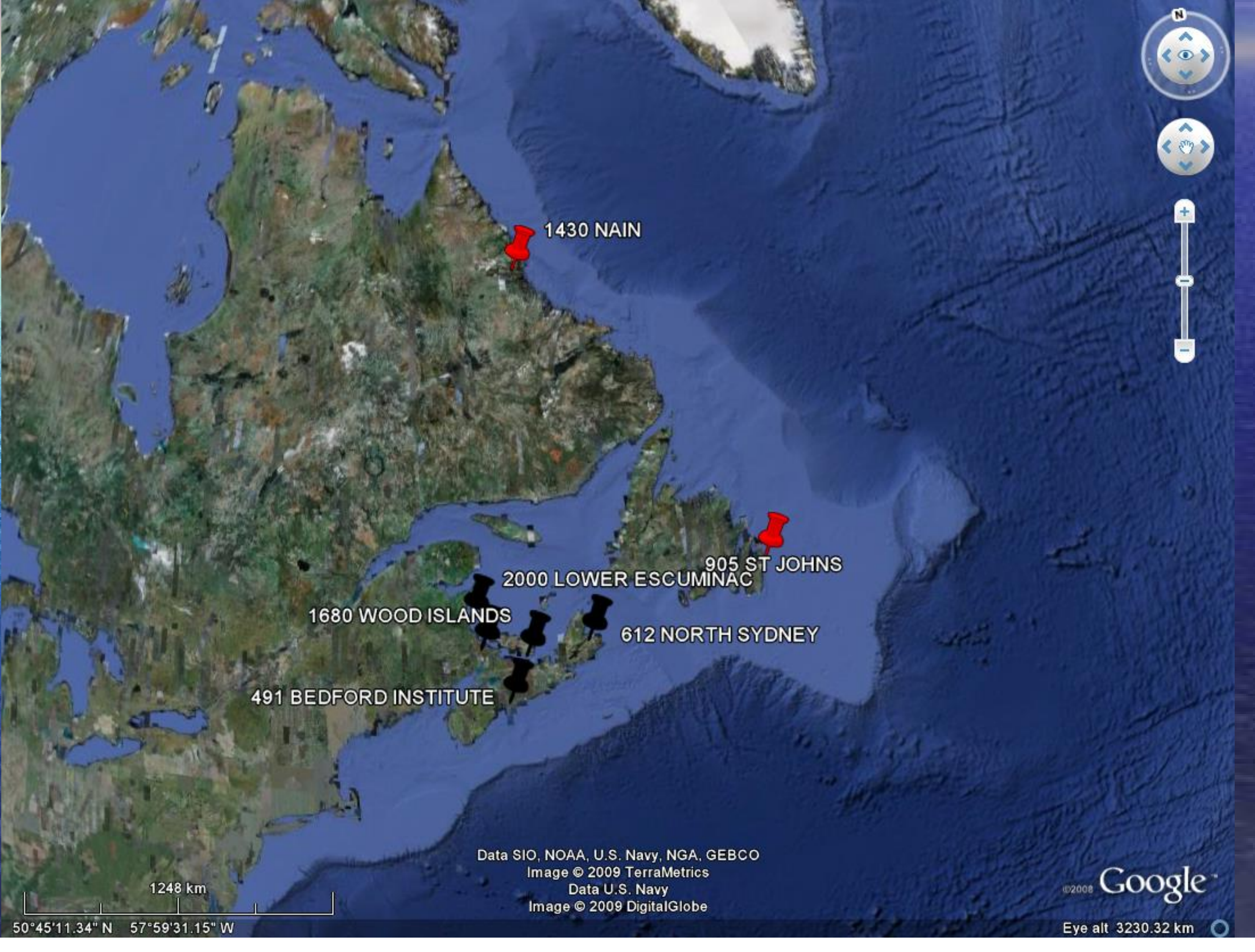


Other 2009-2010 Projects

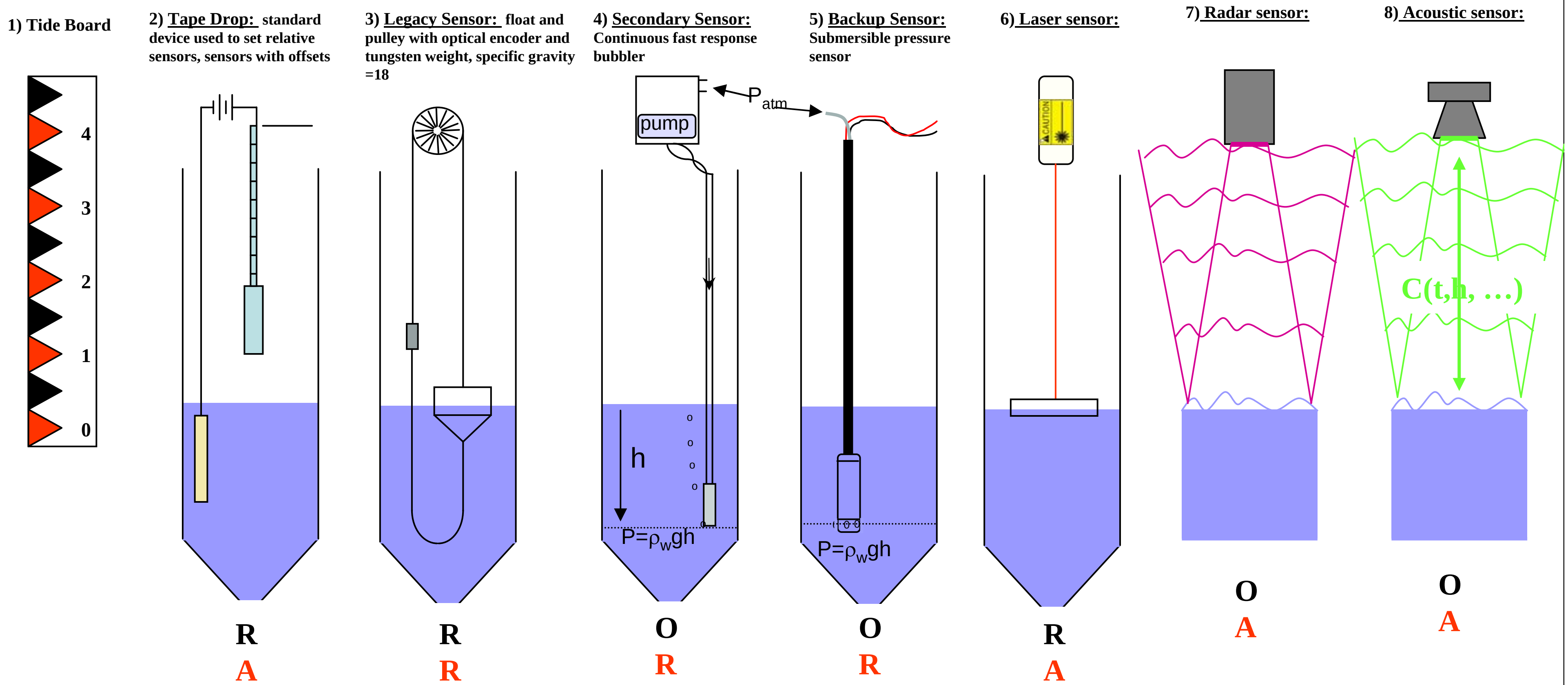
- Migration to LAT for CD, HAT for DE, keep LLWLT for high water datum (appropriate target for flooding)
- Redesign Canadian tide tables to permit:
  - multiple datums, epoch named (CD_{XXXX})
  - change to y=mx+b method for secondary port calculations

A laser-based water level sensor and robust insulated and heated multi-well stilling well system for ice-prone temperate and sub-arctic environments.

(Examples at St John's NFLD and Nain Labrador)



Water level sensors



Stilling wells required – R

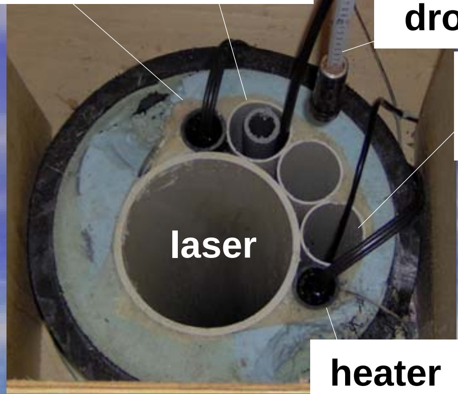
Optional – O

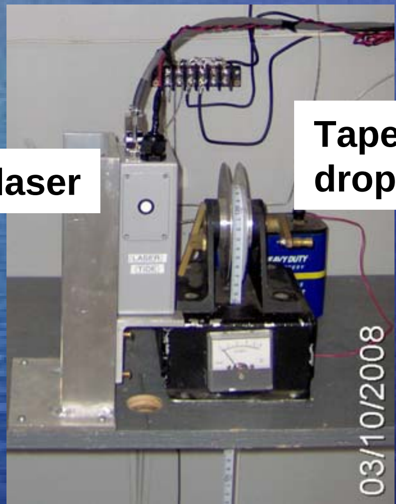
Relative Measurement – R

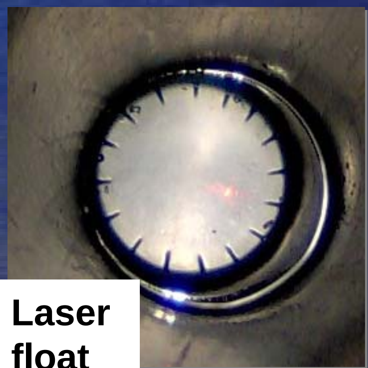
Absolute Measurement -- A

St John's

Stilling Well Assembly

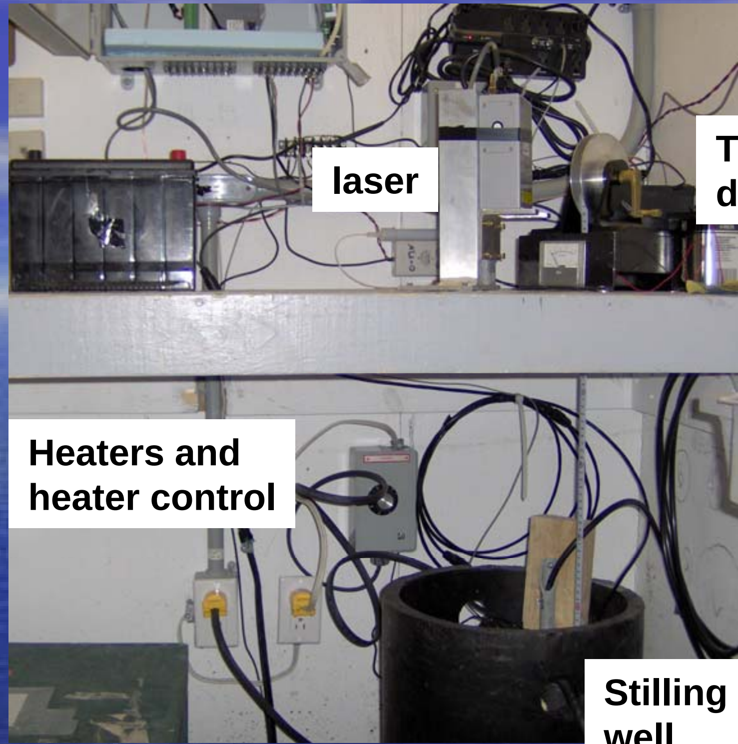




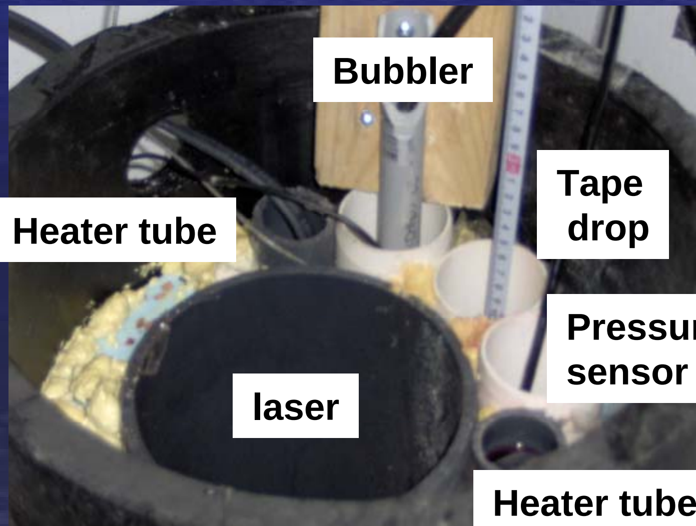


Nain

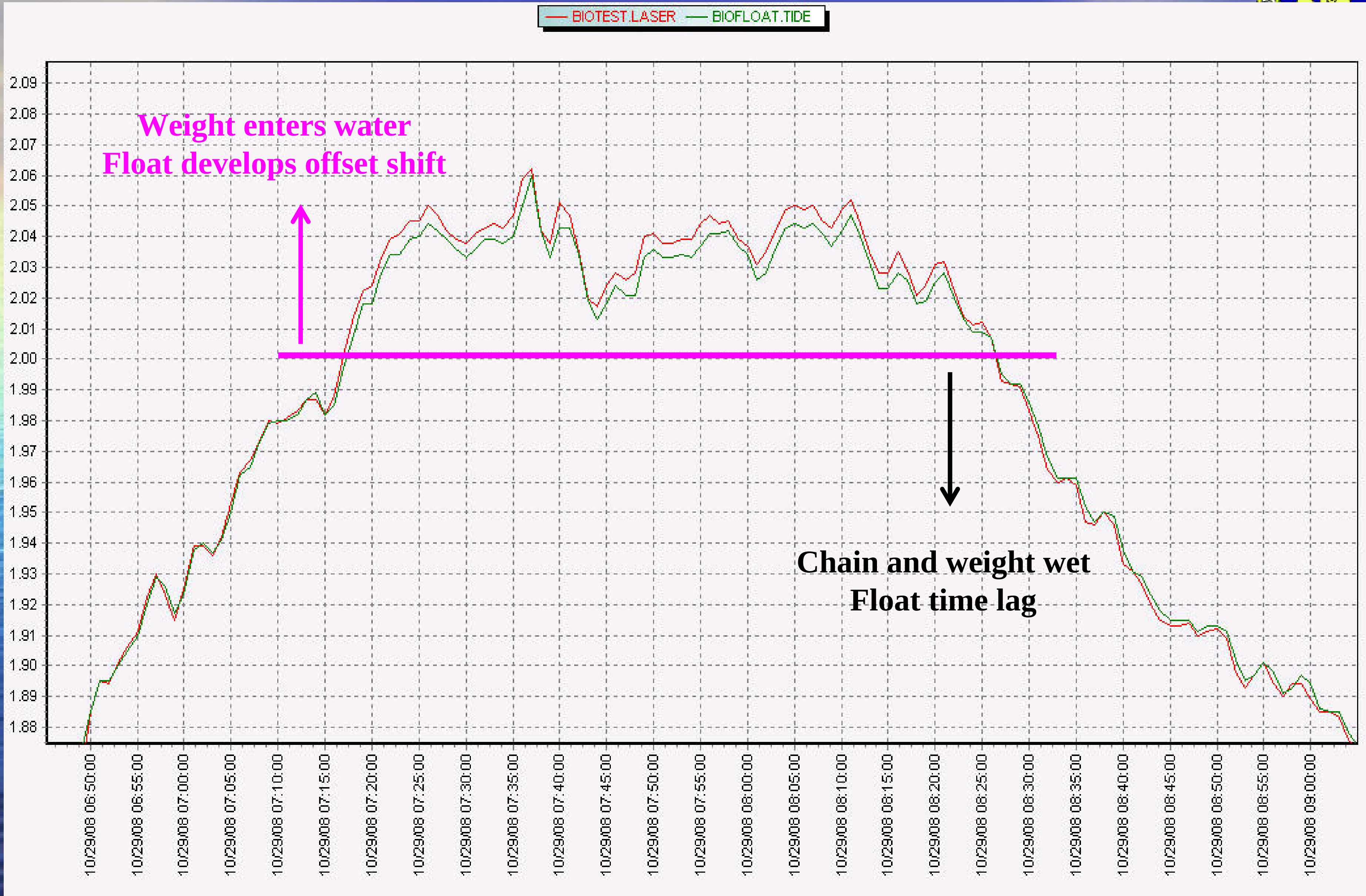

Installing Stilling well


laser
Tape drop
Heaters and heater control
Stilling well


Float installation and removal tool

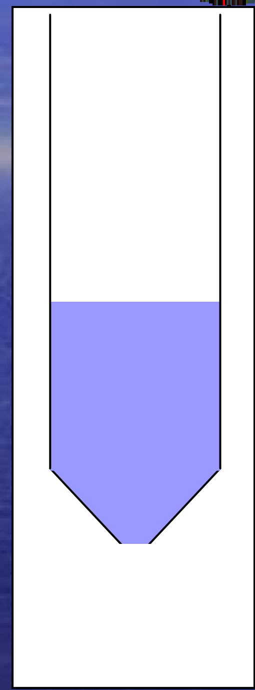

Bubbler
Heater tube
Tape drop
Pressure sensor
laser
Heater tube

Laser vs Float and Pulley

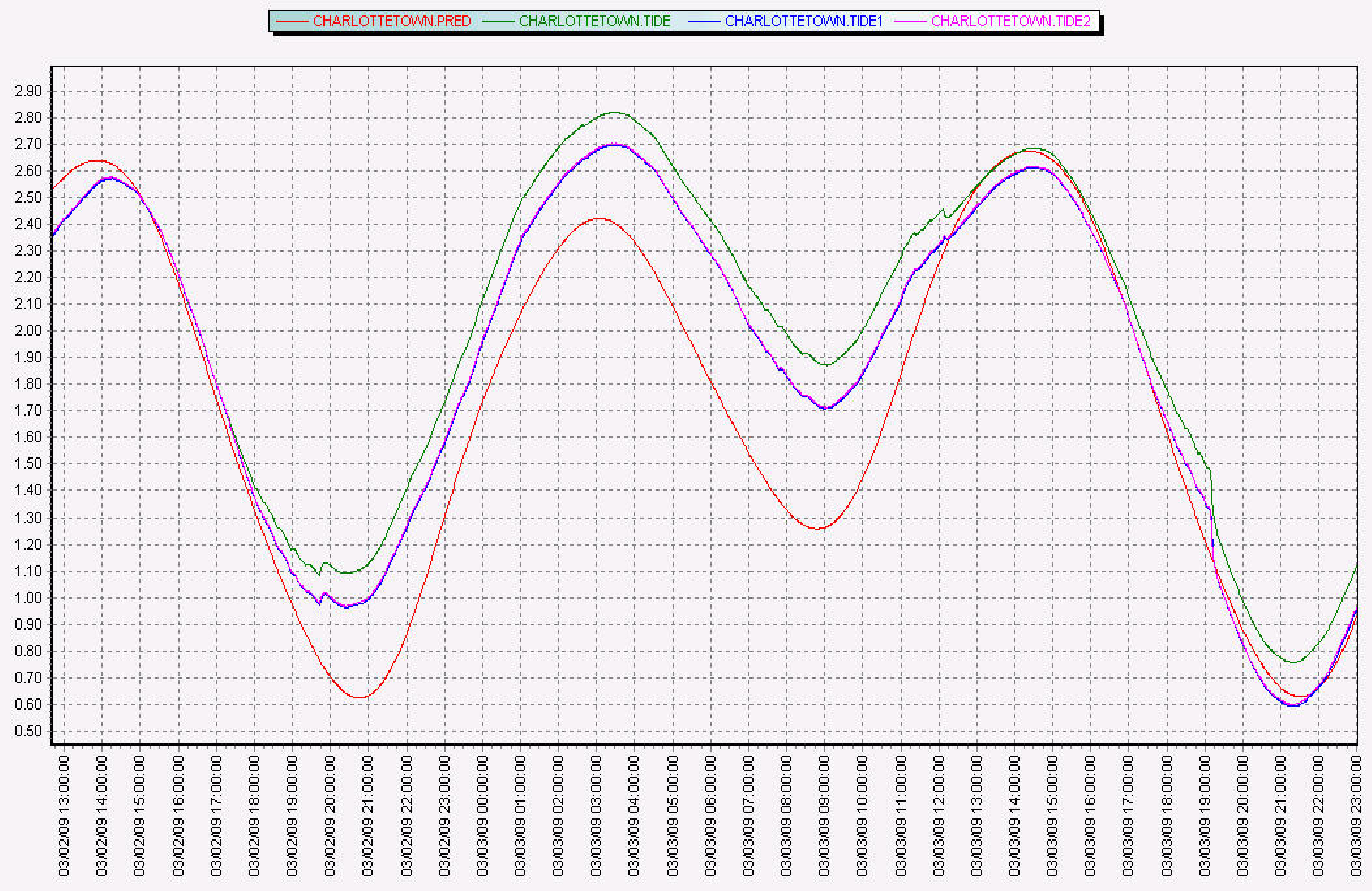


Stilling wells

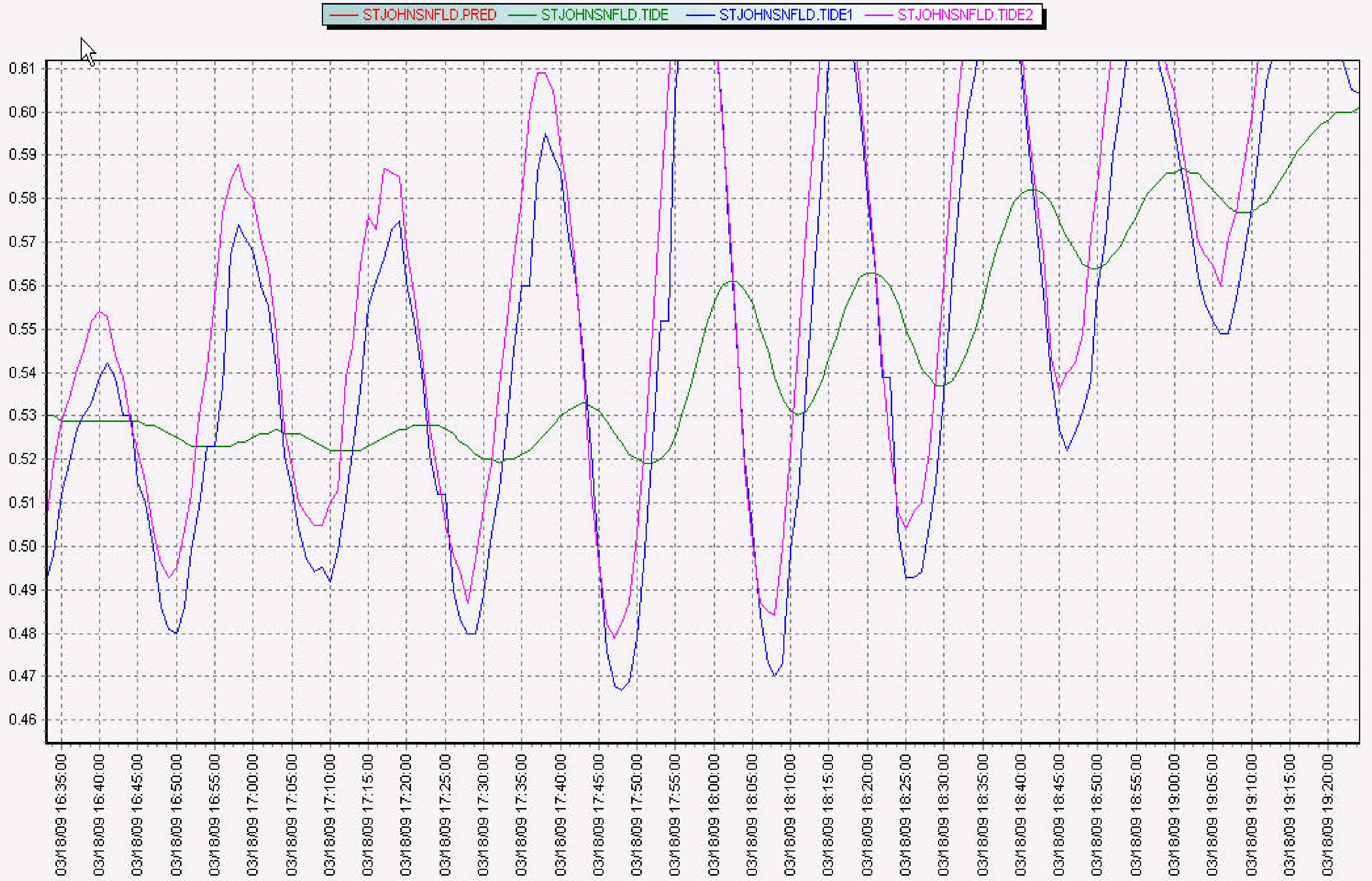
- **Analog filter (small entrance to large tube)**
  - complex frequency dependent filter
  - introduces phase lag
  - filter parameters change with fouling
- **Sensor Protection**
- **Expensive to install and replace**
- **Requires significant vertical infrastructure**
- **Introduces known potential sources of error**
  - water density inside well may not be same as outside, effects water surface position measuring sensors
  - inlet non-linearity can introduce level offset under active wave conditions



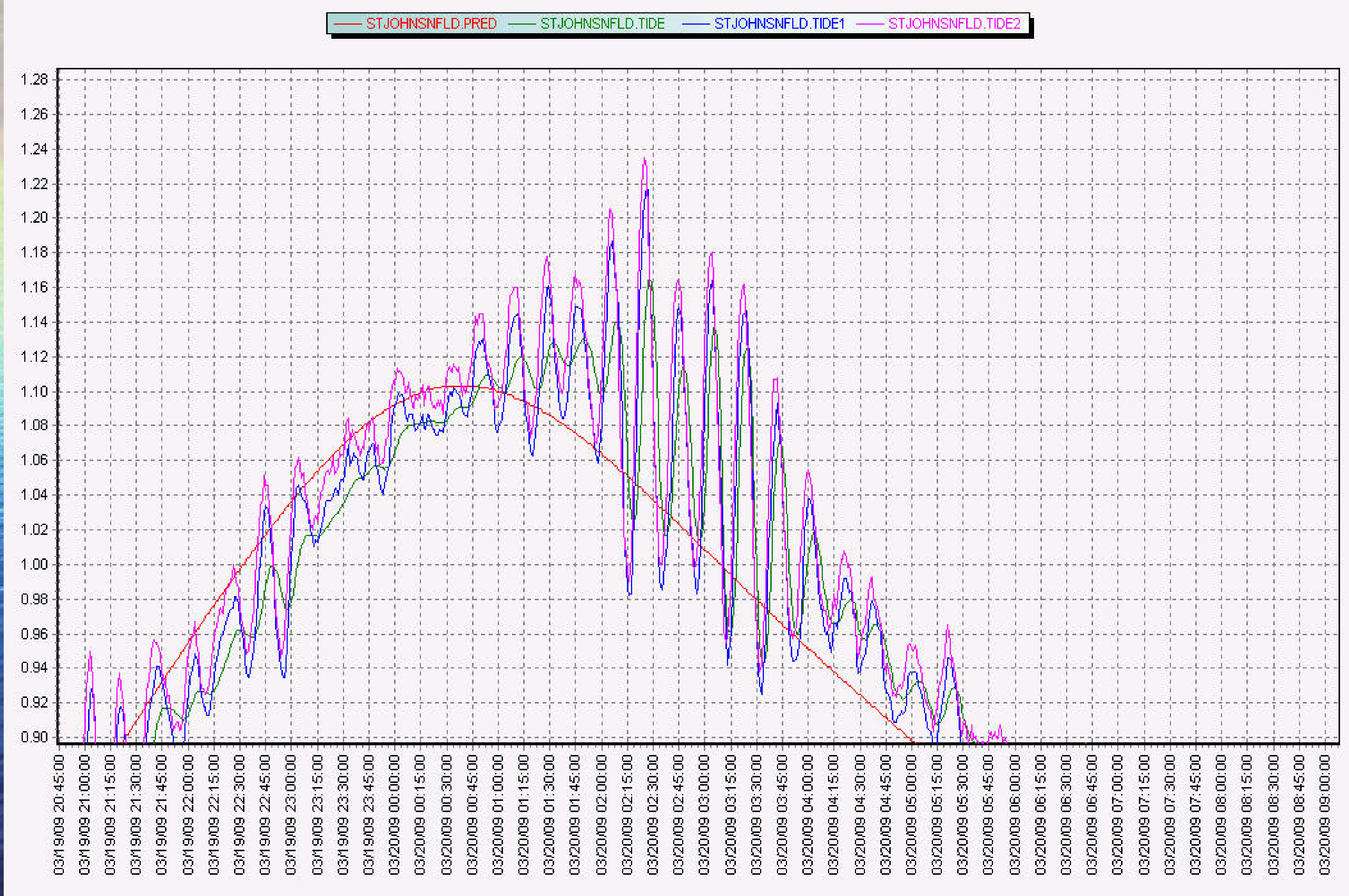
Stilling Well Entraining Fresh Water



Stilling Well Plugging



Stilling Well Unplugging



Low Frequency Waves

Infra-gravity waves, Seiches
Wave amplitudes can reach ~ 1m

Pressure sensors

<u>Method:</u> Strain gauge or quartz crystal oscillator, accuracy (1-3 cm)

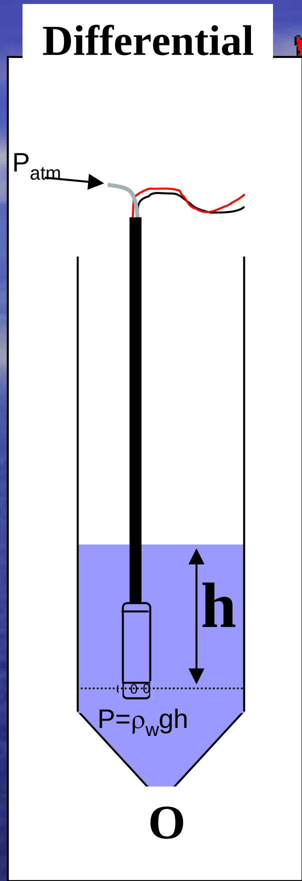
- Two types – absolute and differential
  - absolute (unvented) pressure measurement includes changes in atmospheric pressure $P_g=\rho gh+P_{atm}$
  - differential, atmospheric pressure compensated $P_g=\rho gh$
- Pros: cheap, easy to install, installs under difficult conditions
- Cons:

  both types require knowledge of water density $\rho(z)$

  relative measurement (offset required)

  temperature sensitive (require temperature compensation/calibration)

  sensor drift, fouling



Absolute

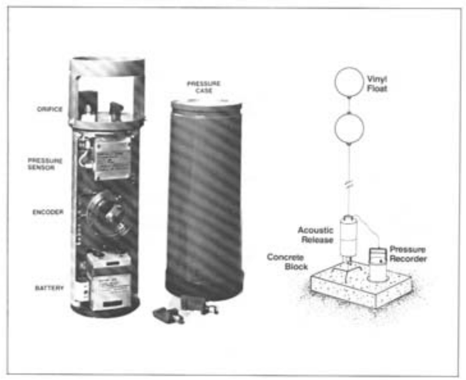
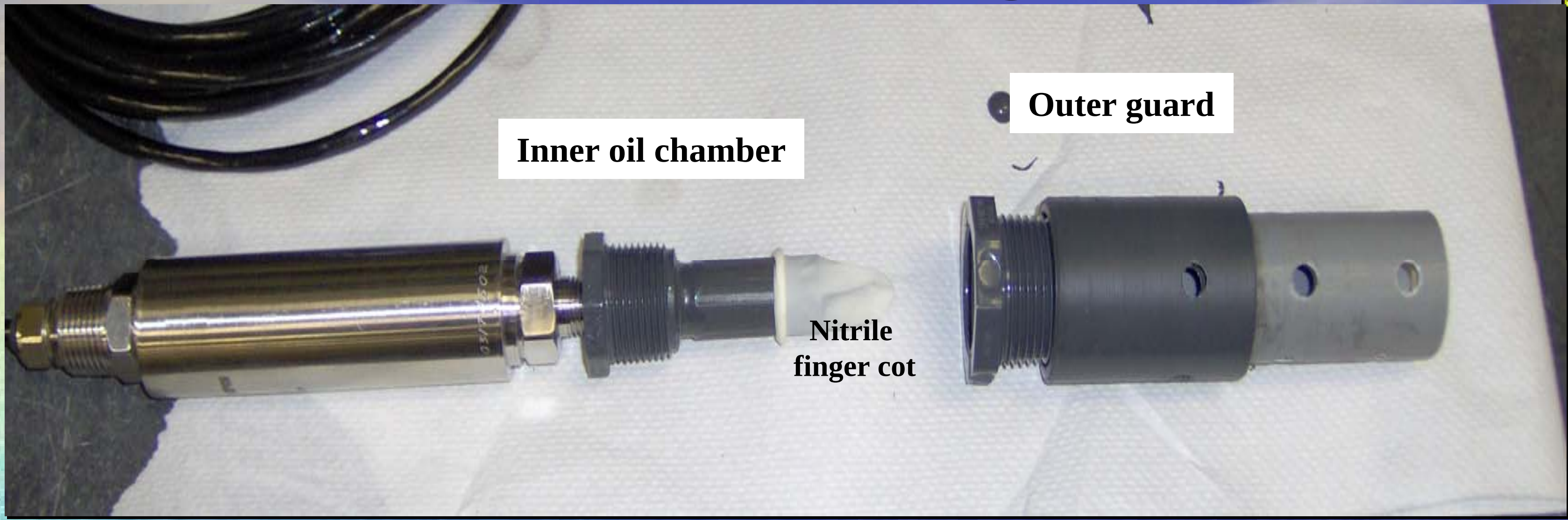


FIG. 3.3. Underwater pressure recorder and mooring arrangement. Water pressure at orifice is recorded internally and stored on magnetic tape. Recovery is effected by activating acoustic release via a surface transmitter; floats then lift recorder from concrete block to surface. (Courtesy Aanderaa Instruments Ltd., Victoria)

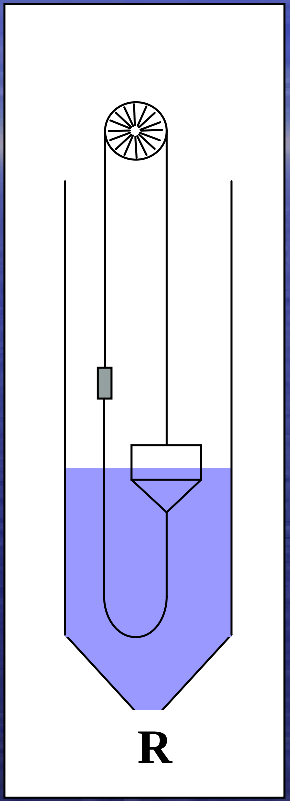
Pressure sensor guard



Float and pulley (optical encoder)

<u>Method:</u> **measure angular turns of chain wheel, accuracy 1-3 cm**

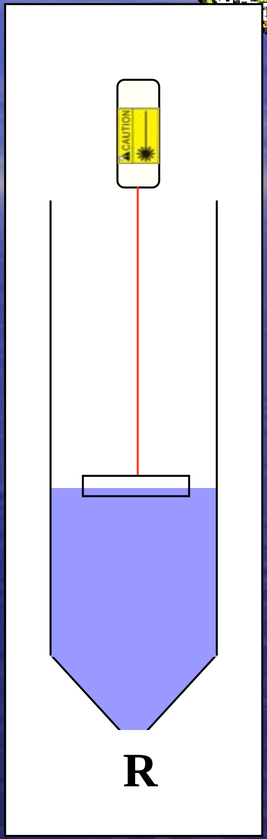
- **Pros:**
  - legacy sensor (used for long time, well known)
  - accuracy to 2-3 mm (maybe)
  - field maintainable
- **Cons:**
  - requires stilling well and stilling well accuracy issues
  - for high accuracy requires special efforts to compensate for chain and weight effects (data corrections, special chain configurations)
  - mechanical, prone to failure by fouling
  - chain slip/skip



Laser float

<u>Method:</u> fast amplitude modulation, phase detection (pseudo time of flight) accuracy (1-2 mm)

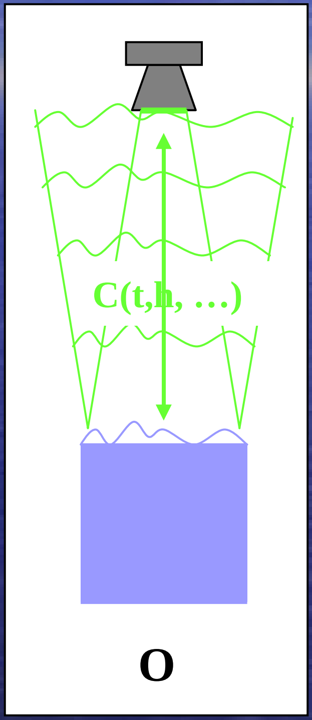
- Pros:
  - absolute measurement
  - highly accurate (1-2 mm)
  - stable, robust, relatively cheap sensor
- Cons:
  - requires stilling well and magnetic float
  - new technique, possible unforeseen issues
  - occasional data spikes, de-spiking occasionally required (possible float color issue, water droplet issue?)



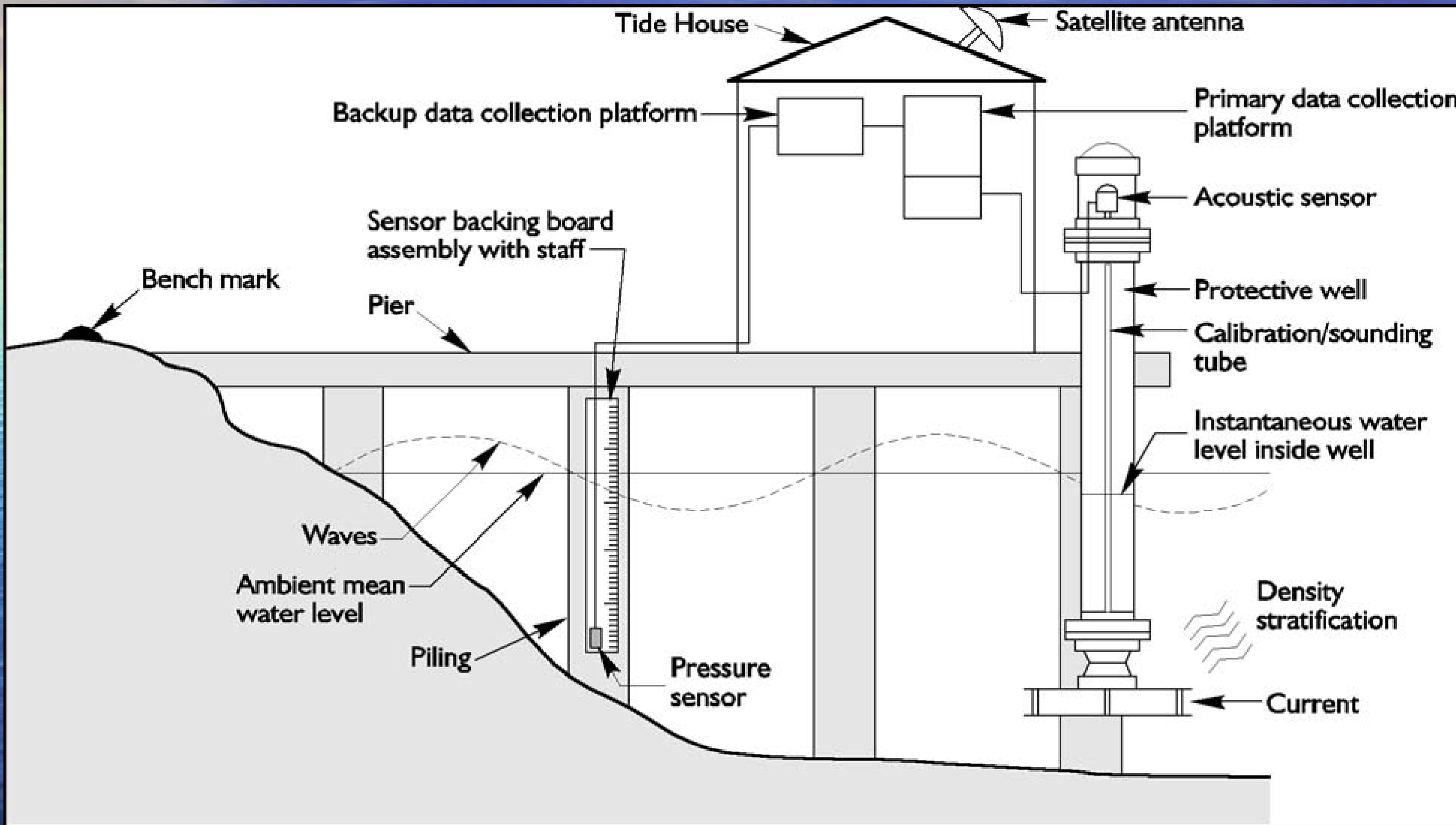
Acoustic sensor

<u>Method:</u> time of flight, various sensor configurations with and without stilling wells, accuracy (1-3cm ?)

- Pros:
  - use without stilling well
  - measures water surface
- Cons:
  - sound speed sensitive to air temperature and humidity, requires constant calibration with integral targets (still have issues with vertical t and h gradients
  - data requires de-spiking, particularly for unprotected installations outside of stilling wells
  - outside installations collect some sort of surface average, but is this a true measure of surface location under wavy conditions?
  - ice or floating material fouls measurement



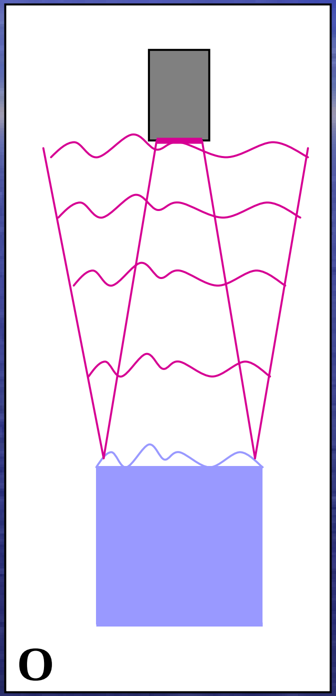
NOAA installation



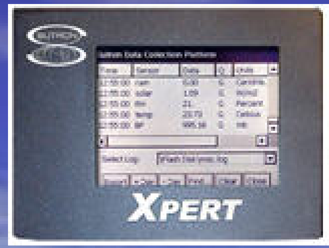
Radar sensor

Method: phase shift or time of flight (wavelenghts from 100m to 1 cm) accuracy (1cm)

- Pros:
  - use without stilling well
  - potentially large measurement range
  - real surface measurement
  - potentially direct measurement
  - Robust device
- Cons:
  - relatively expensive
  - outside installations collect some sort of surface average, but is this a true measure of surface location under wavy conditions? No surface roughness induced offset.
  - exposure to elements



PWLN Equipment



- *New Versatile Sutron XPert Dataloggers*
- *Backup Communications*

  GOES Satellite Systems
- *High Frequency Water Level Measurements and Gauge Polling*

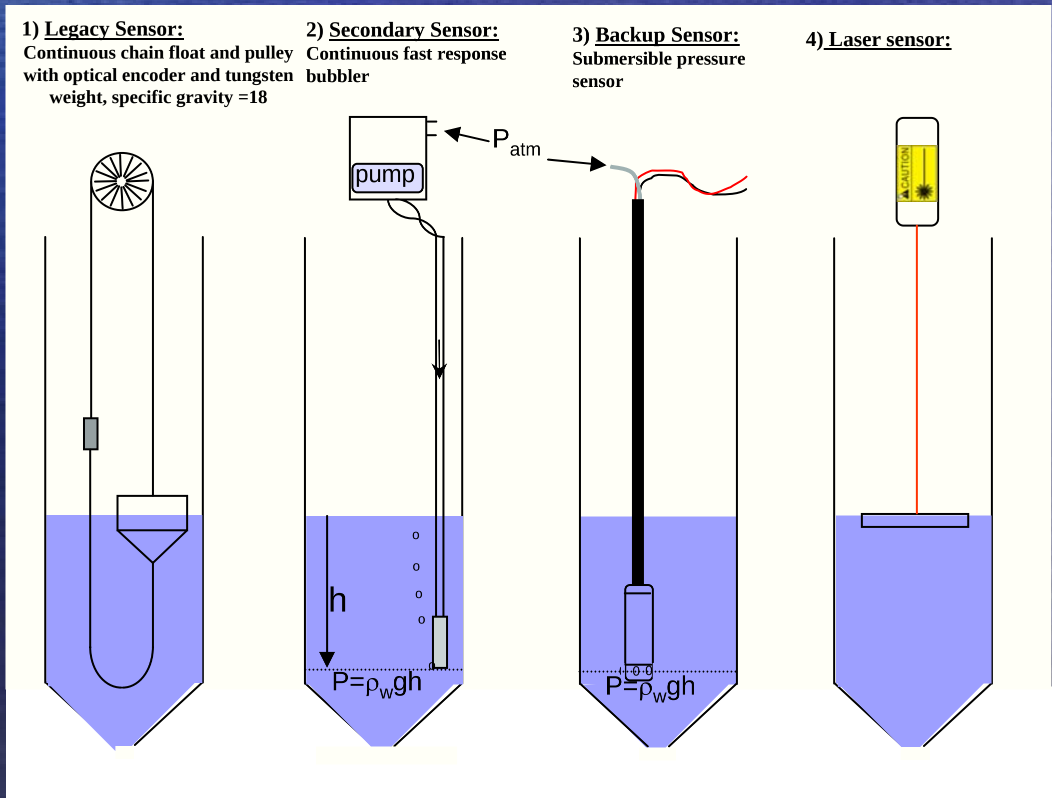
  1 minute averaged sampling, 10 minute gauge polling, average 5 min data latency
- *Sutron XConnect real time data collection software*

- *Redundant Sensors*

  Primary Rotary Encoder
  (Stable, Accurate, Reliable)
  Secondary Bubbler
  (Stable, Secondary Backup)
  Tertiary Pressure sensor
  (Extreme Water Levels,
  Fast Response Wells, Tertiary Backup)

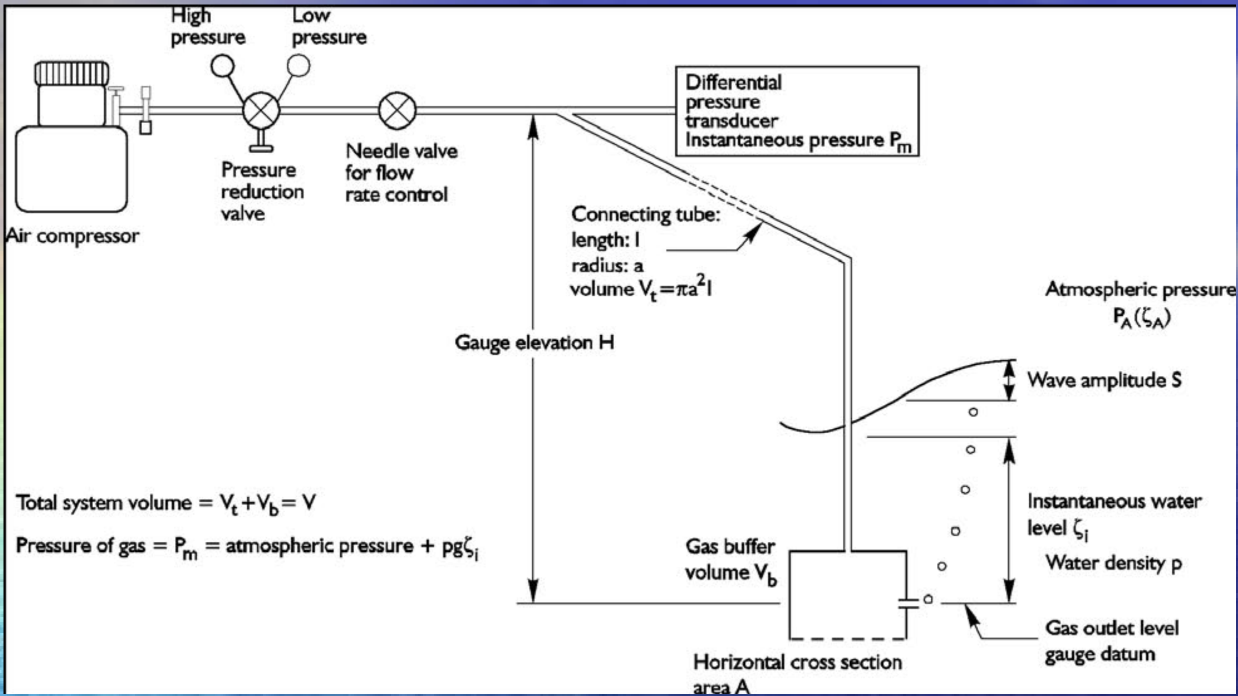
  Who is Crazy?

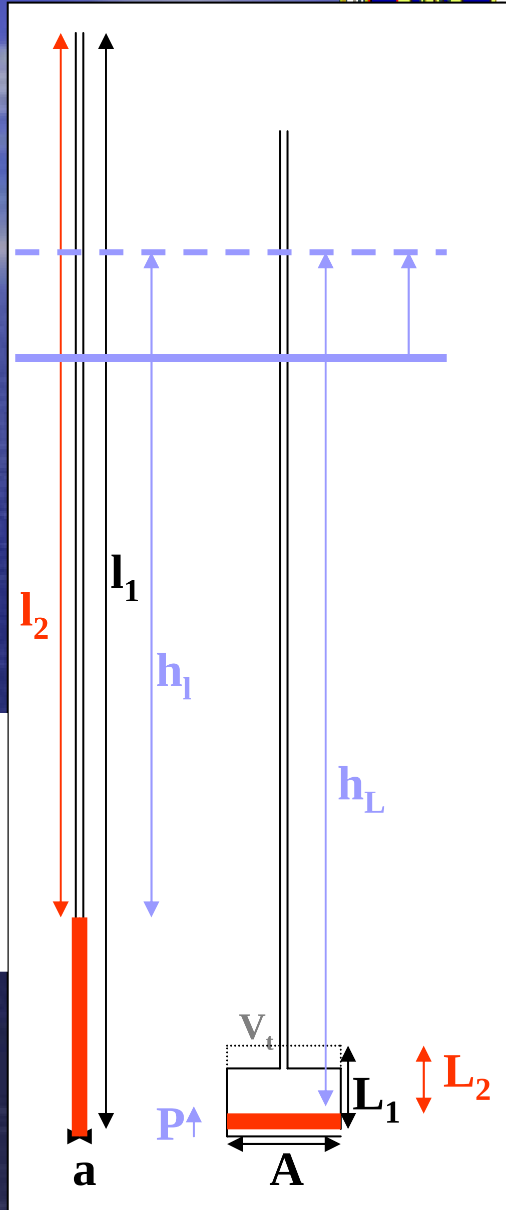
  Laser sensor
  (Stable, Highly Accurate,
  Direct Independent Measurement
  Testing for GLOSS sites)



Bubbler sensor

Why bell housing?





$$PV = nRT = C, \quad (P + \Delta P)(V + \Delta V) = C$$

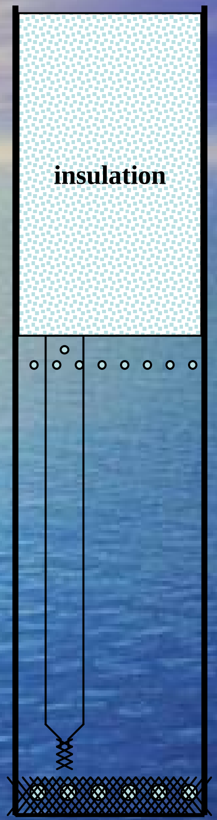
$$PV + P\Delta V + V\Delta P + \Delta V \Delta P = C, \quad P\Delta V + V\Delta P + \Delta V \Delta P = 0$$

small

$$\frac{\Delta P}{P} \cong \frac{-\Delta V}{V} = \frac{-\Delta l}{l} = \frac{-\Delta L}{L}, \quad \Delta l = (l_2 - l_1), \Delta L = (L_2 - L_1)$$

Pros: stable precision, robust, installs in difficult locations, accuracy 1-3 cm

Cons: expensive, water density required, can be complicated, relative measurement (offset required)


insulation