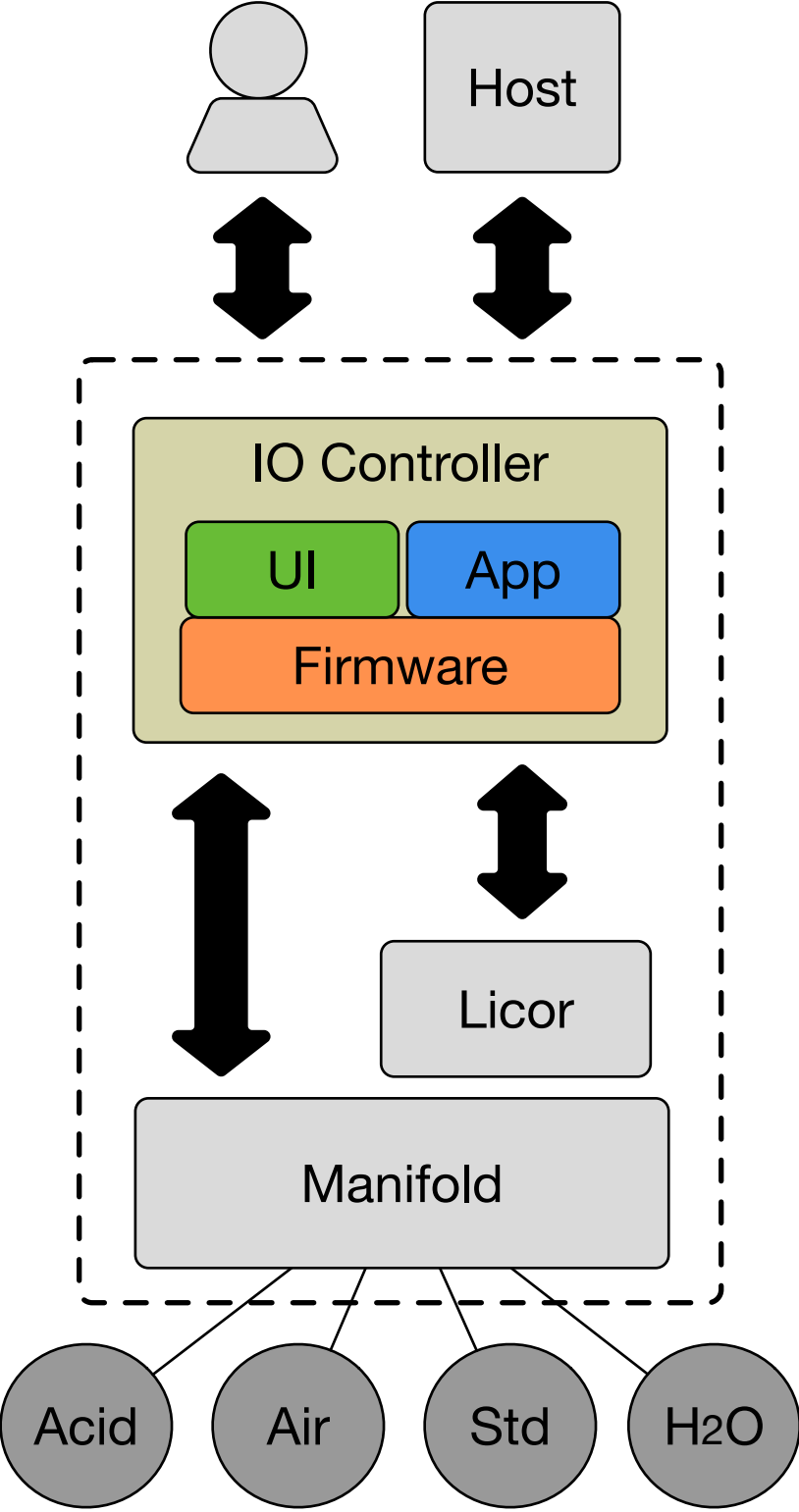




System components

IO controller : General purpose, low-power

Software : Generic firmware + UI + application-specific

Software Functions

- Control IO for fluid, gas handling**
- Implement programmable sampling logic**
- Summarize, log, review Licor measurements**

System Features

RS232	3
User Digital IO	23
ADC	2
RTC	Maxim DS3234S ±2ppm from 0°C to +40°C
Timer resolution	10 ms
SD Card	32 GB
Processor	PIC24FJ1024GA606 @ 4MHz
Flash	1024 kB
SRAM	32 kB
Development	Microchip MPLabX v5.10 XC16 C compiler

UI, Scripting	IO control API Conditional branching Variable-substitution Numeric register variables, operators Print functions multiple scripts (single threaded) Periodic scheduler FatFs ASCII file upload File-based configuration, logging File pager, w/ find (e.g. less/more) System help Command history Inspect, change, export configuration Last sample queue Diagnostics Automatic sleep , sampling wakeup
File IO	
Convenience features	
Power management	

Firmware exposes functional building blocks

Flexible, Extensible

Human/Machine friendly

Limited scope

API fully expresses IO, sampling operations, timing and logic

Scripted operation, stateless or (potentially) stateful

Simple APIs for extending UI, processing code

Broad compatibility with data work flows

Serial console

Simple command line interface == script API

Interactive, stand-alone or hosted operation

Synchronous or asynchronous output

CSV ASCII data formats

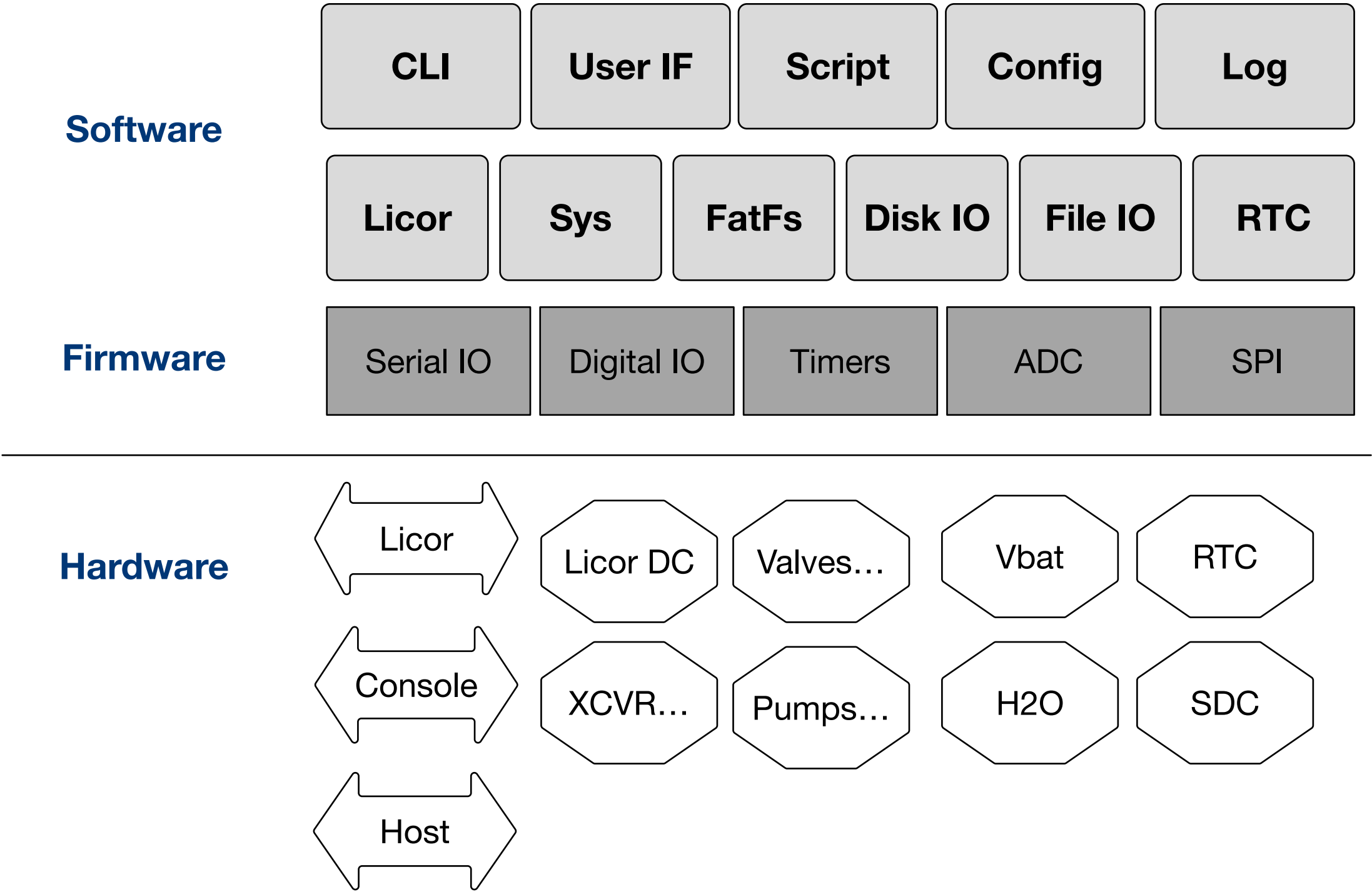
Not a...

General purpose data logger/controller

High performance computing platform

Telemetry endpoint

Core Software Modules



Measurement Cycle

During a **measurement cycle**, several **conditions** are measured:

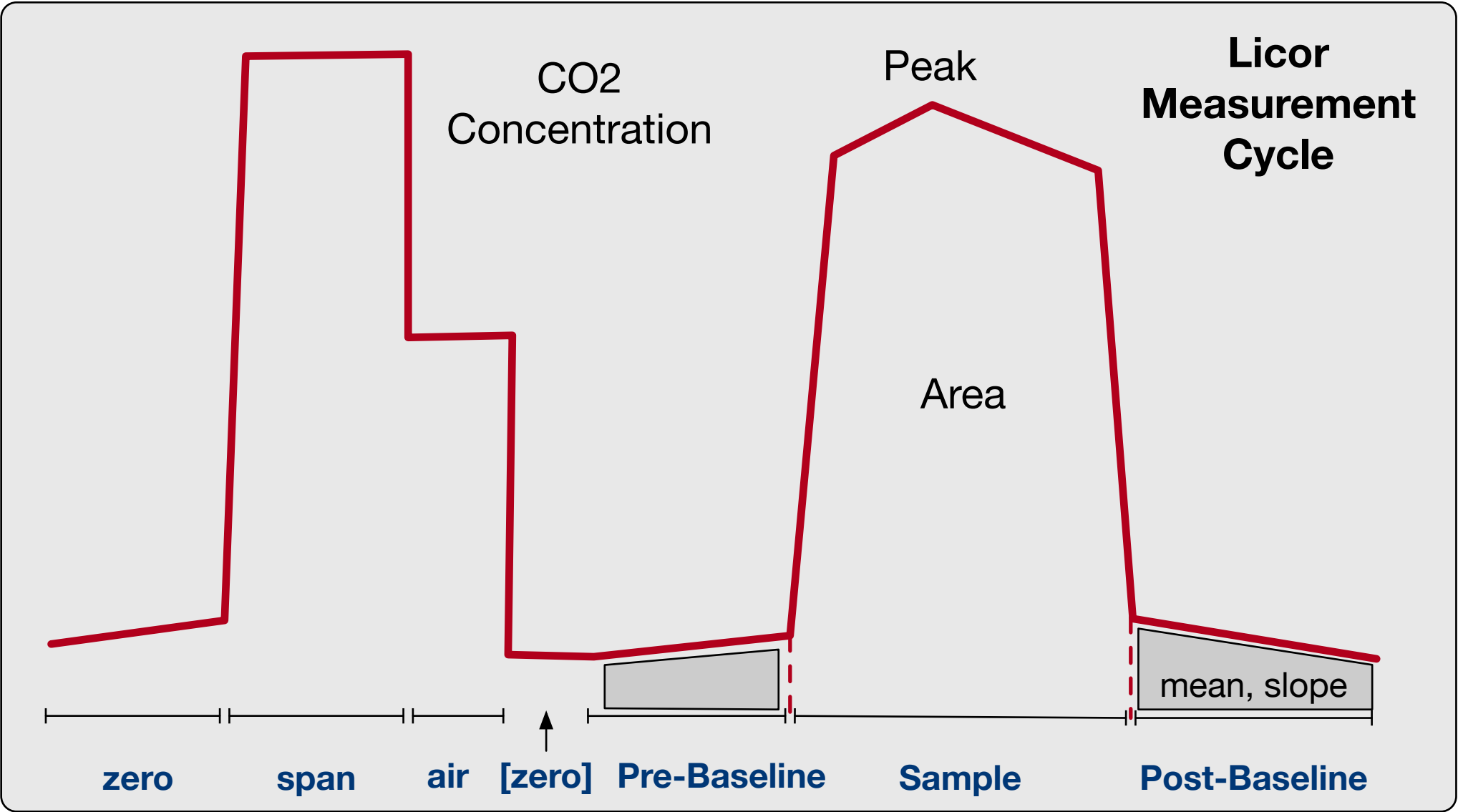
- zero
- air
- span
- baseline (pre/post sample)
- sample

For each condition, multiple Licor samples are taken, containing several **parameters**:

- co2, co2raw, co2ref, celltemp, cellpres, h2o, etc.

Various **measurements** are taken for a set of parameters, which varies per-condition:

- Mean, Sdev, area, slope, etc.



Constraints

Licor outputs XML - high data volume

Can strip XML, but format apparently undocumented

SD Card access is relatively slow

Impractical to buffer, telemeter raw data

Temperature, salinity not available at sampling time

Sampling Plan

In-line stream processors **summarize data**

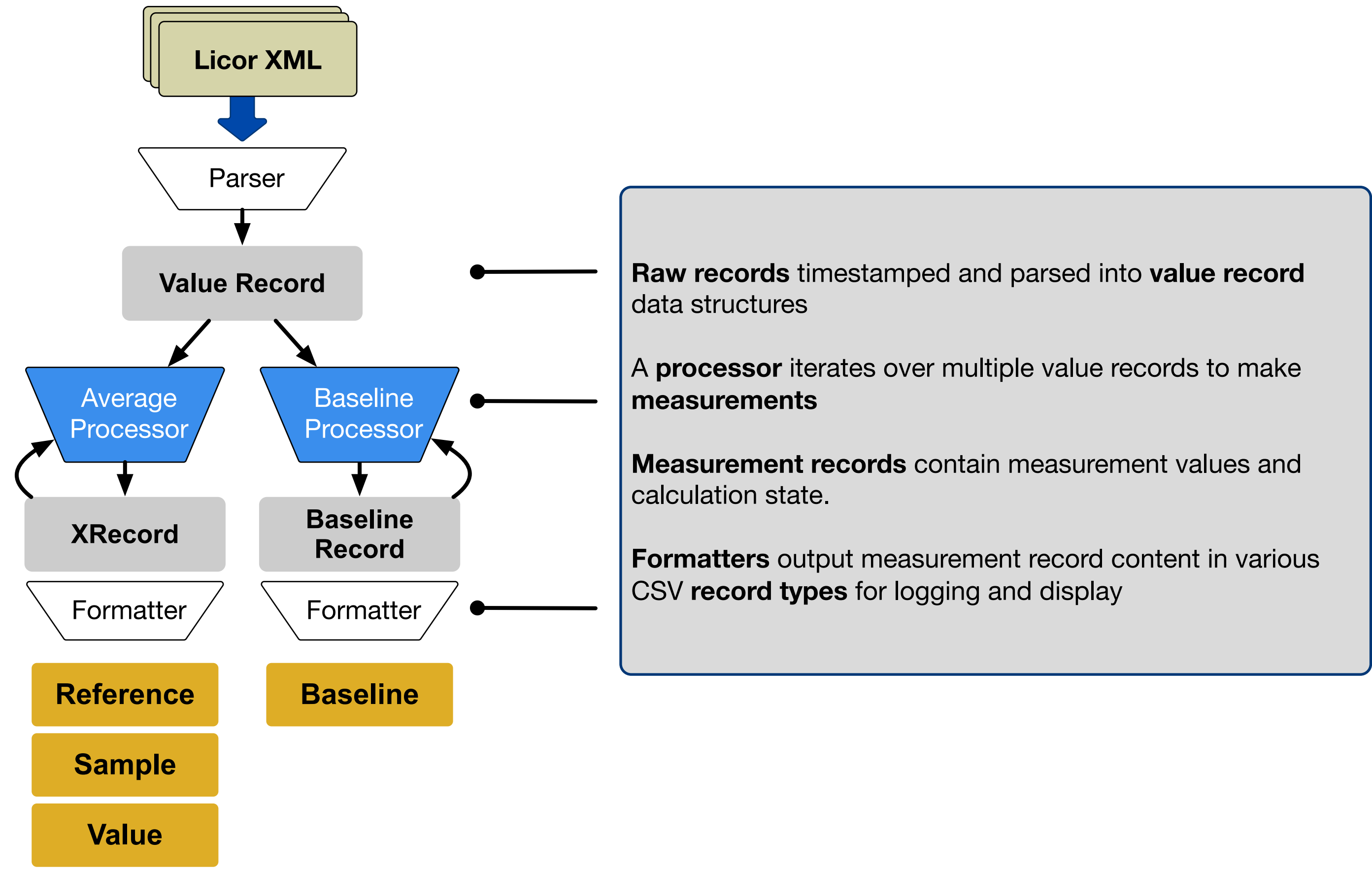
Log, return summary records to host

Log and post-process raw (XML) data

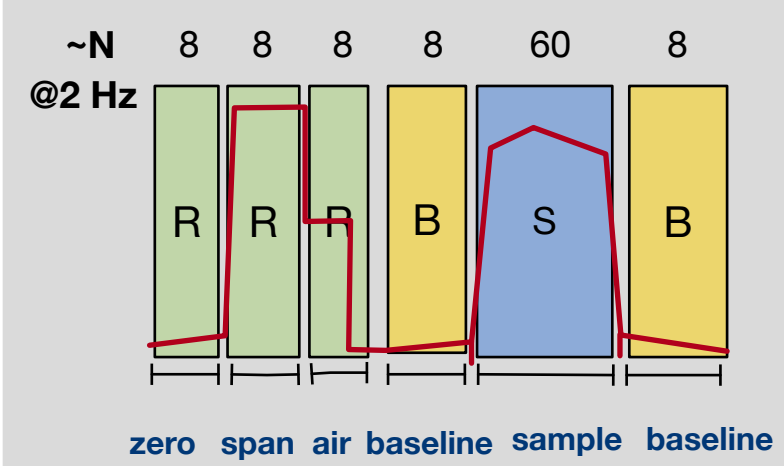
Timestamp all data

Implement **additional processing, telemetry externally**

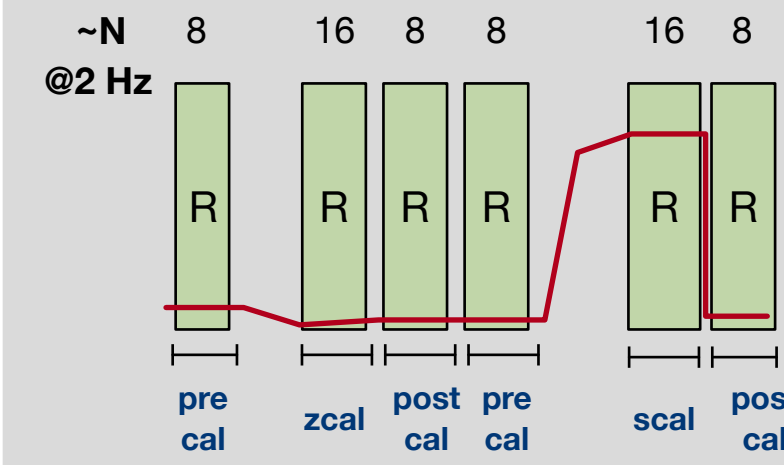
Processing Pipeline



Record Content

Record Type	Measurements	Parameters	
Value V	VALUE[6]	co2, co2abs, h2o, h2odewpoint, h2oabs, celltemp, cellpres, ivolt, flowrate, rawco2, rawco2ref, rawh2o, rawh2oref	Measurement Cycle 
Reference R	N MEAN[13] SDEV[13]	co2, co2abs, h2o, h2odewpoint, h2oabs, celltemp, cellpres, ivolt, flowrate, rawco2, rawco2ref, rawh2o, rawh2oref	
Baseline B	N MIN MAX MEAN SDEV SLOPE OFFSET R ²	co2	
Sample S	N MEAN [6] SDEV [6] PEAK AREA [1]	[6] [co2, co2raw, co2ref, celltemp, cellpres, h2o] [1] [co2]	

Cal Cycle



Logging Overview

Raw

- Licor XML

Summary

- Licor measurement summaries
- Mixed record types

System

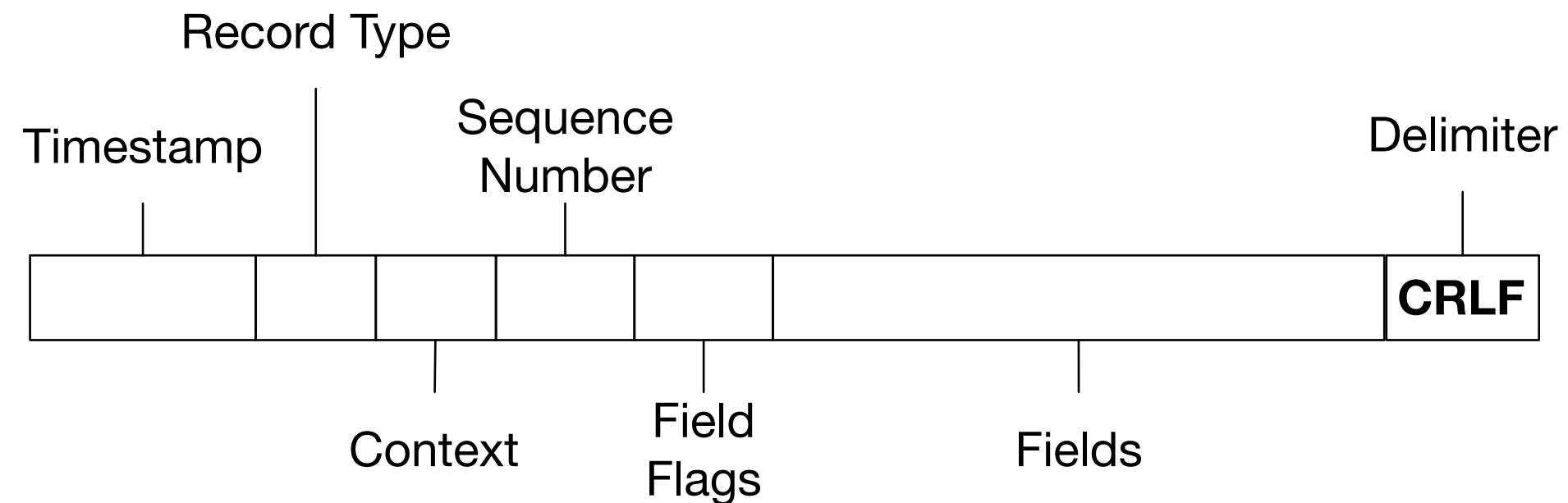
- System status, errors, etc.

- **3 Logs: Raw, Summary, System**
- **Timestamped**
- **ASCII**
- **CSV**

File Encoding
Record Format
Record Delimiter
Timestamp
File System
File Names
Segmentation
Indexed
Record IDs

ASCII, UTF-8
CSV
CRLF (0x0D0A)
ISO8601, Posix
FatFs
DOS (case insensitive, 8.3)
date, size (optional)
No
Self-identifying

Record Structure



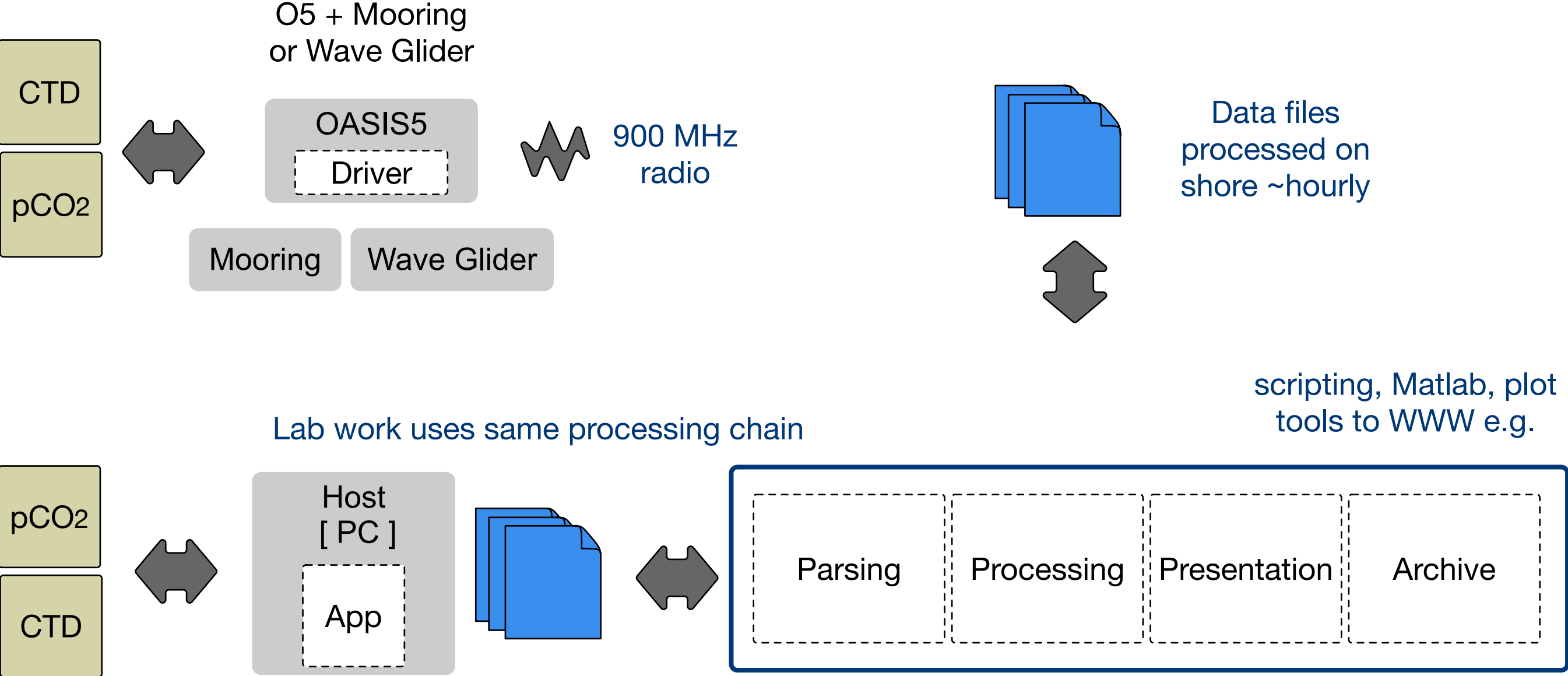
Timestamp	ISO8601 and/or Epoch MS	2019-05-20T08:58:41Z
Record Type	Byte indicating type of record	B: baseline R: ref S: sample V:value ?:default
Context	Byte indicating record context	Z: zero S: span A: air M: meas ?:default
Sequence Number	Sample number	32-bit unsigned integer
Field Flags	Bit field identifying included fields	0x0 - 0xFFFFFFFF
Fields	comma-separated data	format varies
Delimiter	record separator	CRLF (0x0D0A)

Example: baseline record

2019-05-02T08:49:51Z,B,M,123,10,1556786991500,9.246020e-01,1556786996000,8.760600e-01,0.871,0.945,0.911,0.027

Processing

2020: piggyback O5 host on mooring or wave glider - reduces power, simplifies integration
out years: integrate directly with wave glider, other platforms



Status

Core capabilities in place
Developing sampling method
Host, data format/algorithms options open

Current Focus

Host software : OASIS, Lab
Processing software, workflows
Iterate on in-situ algorithms and data formats
Telemetry

Questions?

Topics of Interest

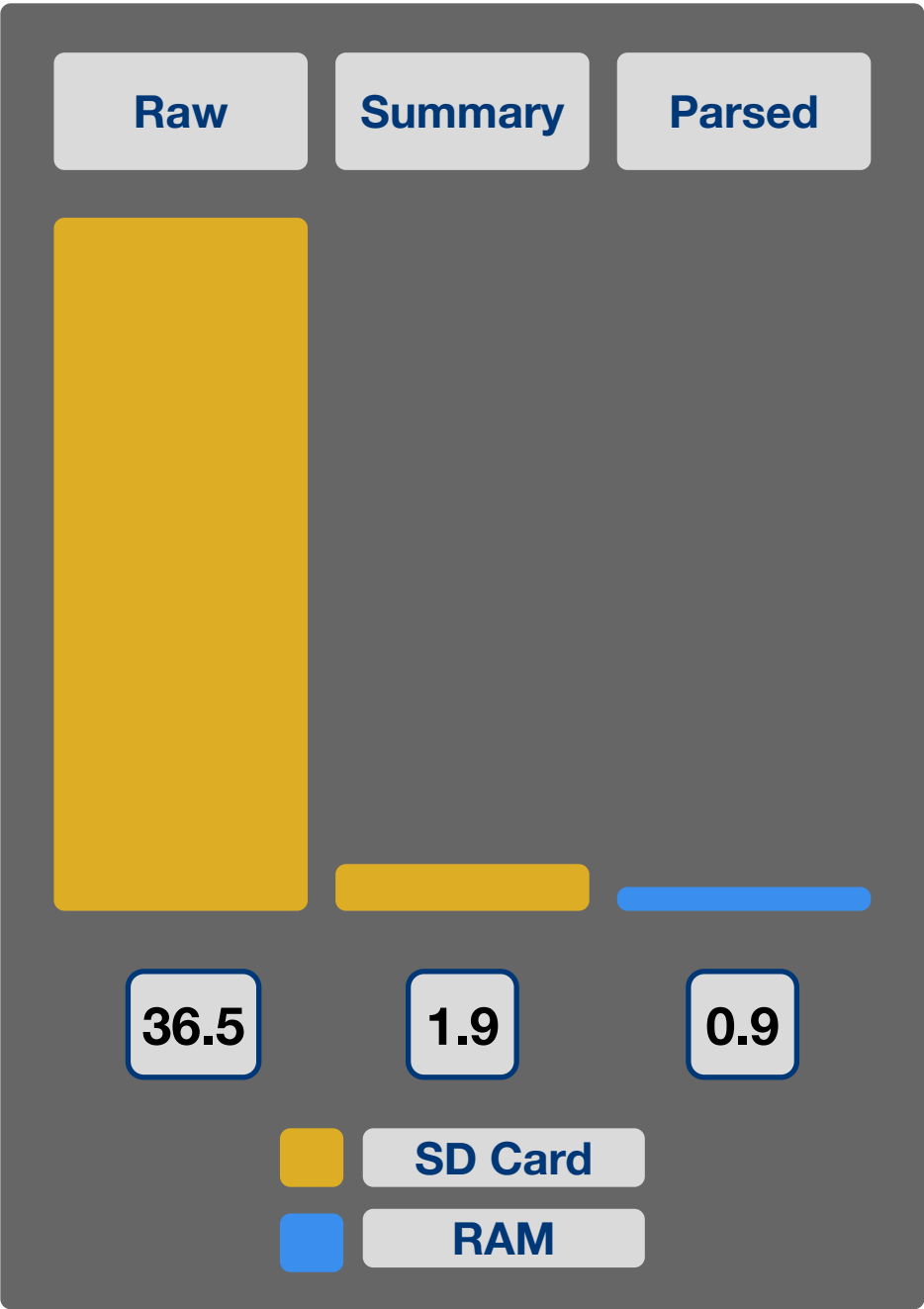
PMEL platform architecture
PMEL data workflows and data
format requirements

Data Volume - measurement

Measurement Cycle

Type	N	Size	Total	Context
raw	100	~365 bytes	36500 bytes	Zero [8], Pre[8], Atm[8], Span[8], Meas[60], Post[8]
bline_record	2	~80 bytes	160 bytes	Pre, Post
x_record	3	~180 bytes	720 bytes	Zero, Atm, Span, Meas
B R S	2	~160 bytes	320 bytes	Pre, Post
	3	~380 bytes	1140 bytes	Zero, Atm, Span
	1	~410 bytes	410 bytes	Meas
Diag	1	~65 bytes	65 bytes	

Data Volume
(kB/cycle)

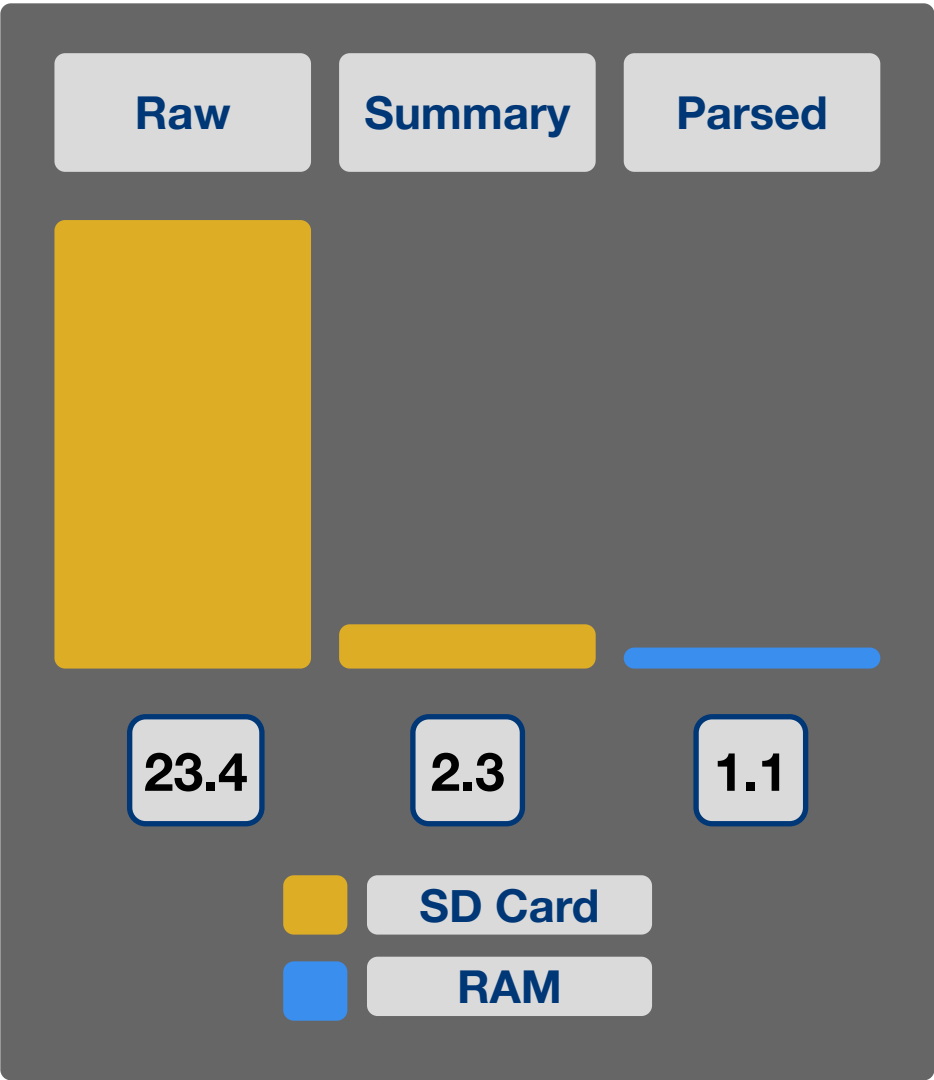


Data Volume - calibration

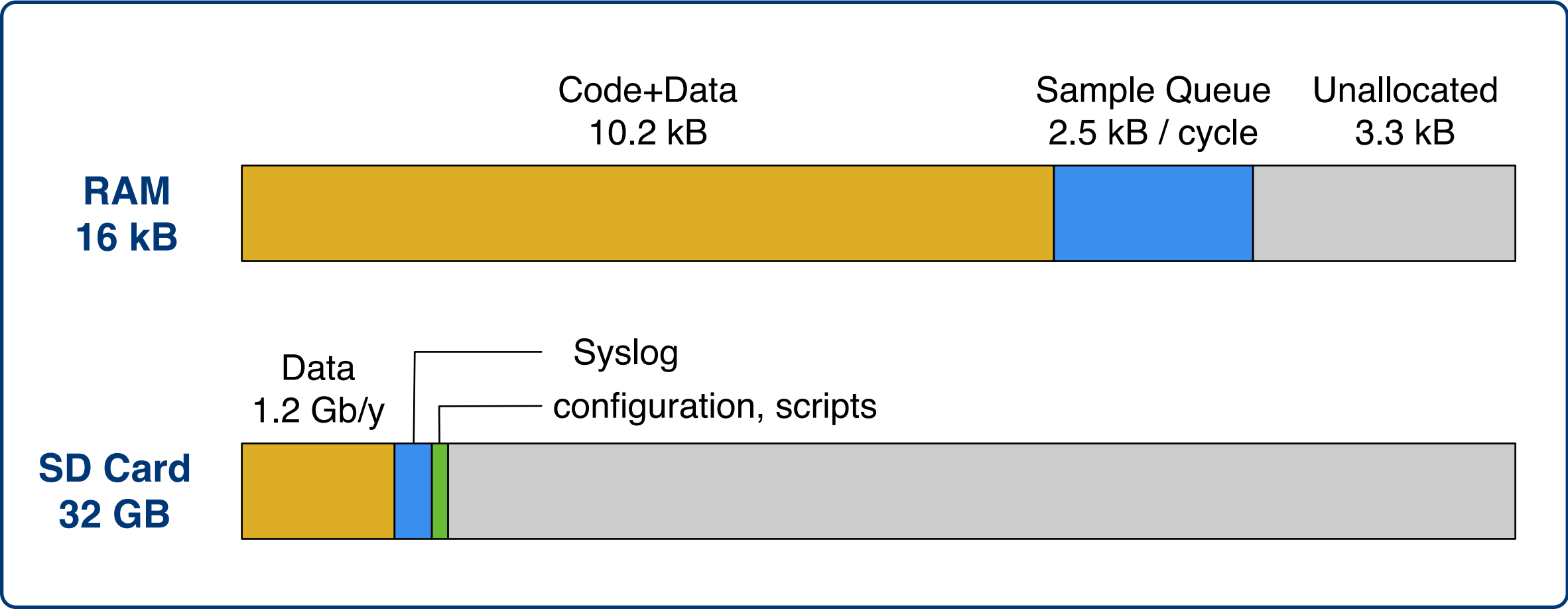
Calibration Cycle

Type	N	Size	Total	Context
raw	64	~365 bytes	23360 bytes	2xPre[8], zero[16], span[16], 2xPost[8]
x_record	6	~180 bytes	1080 bytes	Pre, Post, Zero, Atm, Span
R	6	~380 bytes	2280 bytes	Pre, Post, Zero, Atm, Span

Data Volume
(kB/cycle)



Memory



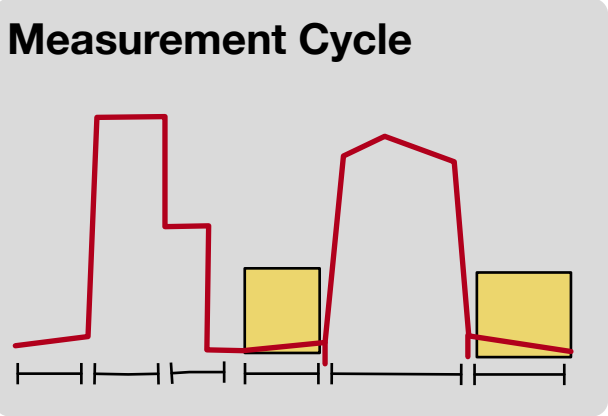
Raw data buffering & telemetry

- Data buffer capacity RAM-limited
- RAM content doesn't persist across power cycles
- SD Card access is slow compared to RAM
- Buffer in flash? maybe...software size, reliability

Data Storage

Cycle	Cycles/d	Storage/d		
Measurement	72	R	S	Total
Calibration	24	2.56M	0.14M	2.7M
		0.56M	0.06M	0.6M
		3.1M	0.2M	3.3M/d

Baseline Measurement



Baseline Measurement

Inputs

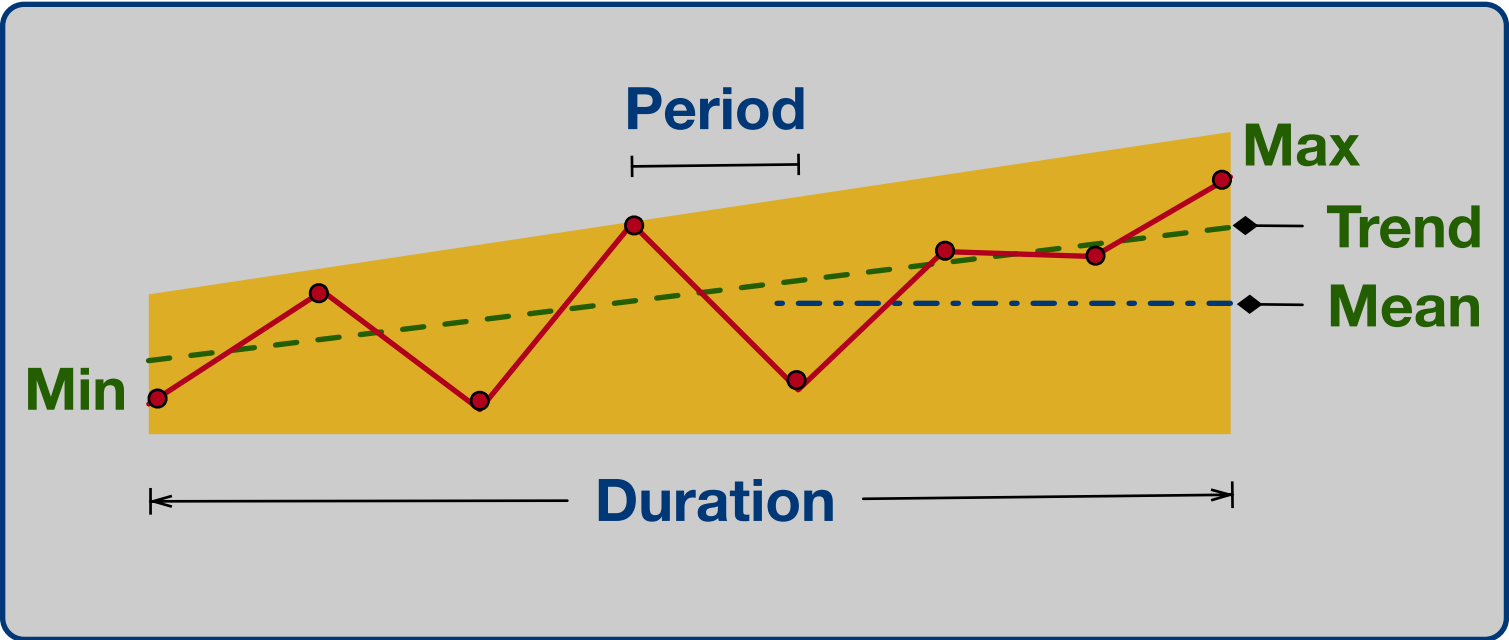
Period : ≥ 0.5 (0.5 s intervals)
Duration : $N / t / F()$
Dest. : Host|Console|Log

Outputs

Trend : m, b, r^2
Min : CO2
Max : CO2
Mean : CO2 [1]
Sdev : CO2 [1]

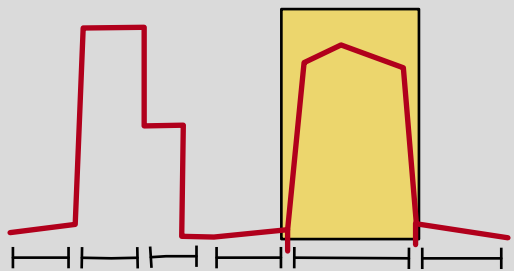
[1] - average computed using Welford's method (single pass, i.e. uses only current, previous samples, reduces over/under flow)

Baseline CO2 averages are taken at the beginning and end of measurement cycles to characterize sensor bias drift.



Sample Measurement

Measurement Cycle



Average Measurement

Inputs

Period : ≥ 0.5 s (≤ 2 Hz)
Duration : $N / t / F()$
Dest. : H|C|L

Outputs

Mean : all [2, 3]
Area : CO2 [1]
Peak : CO2

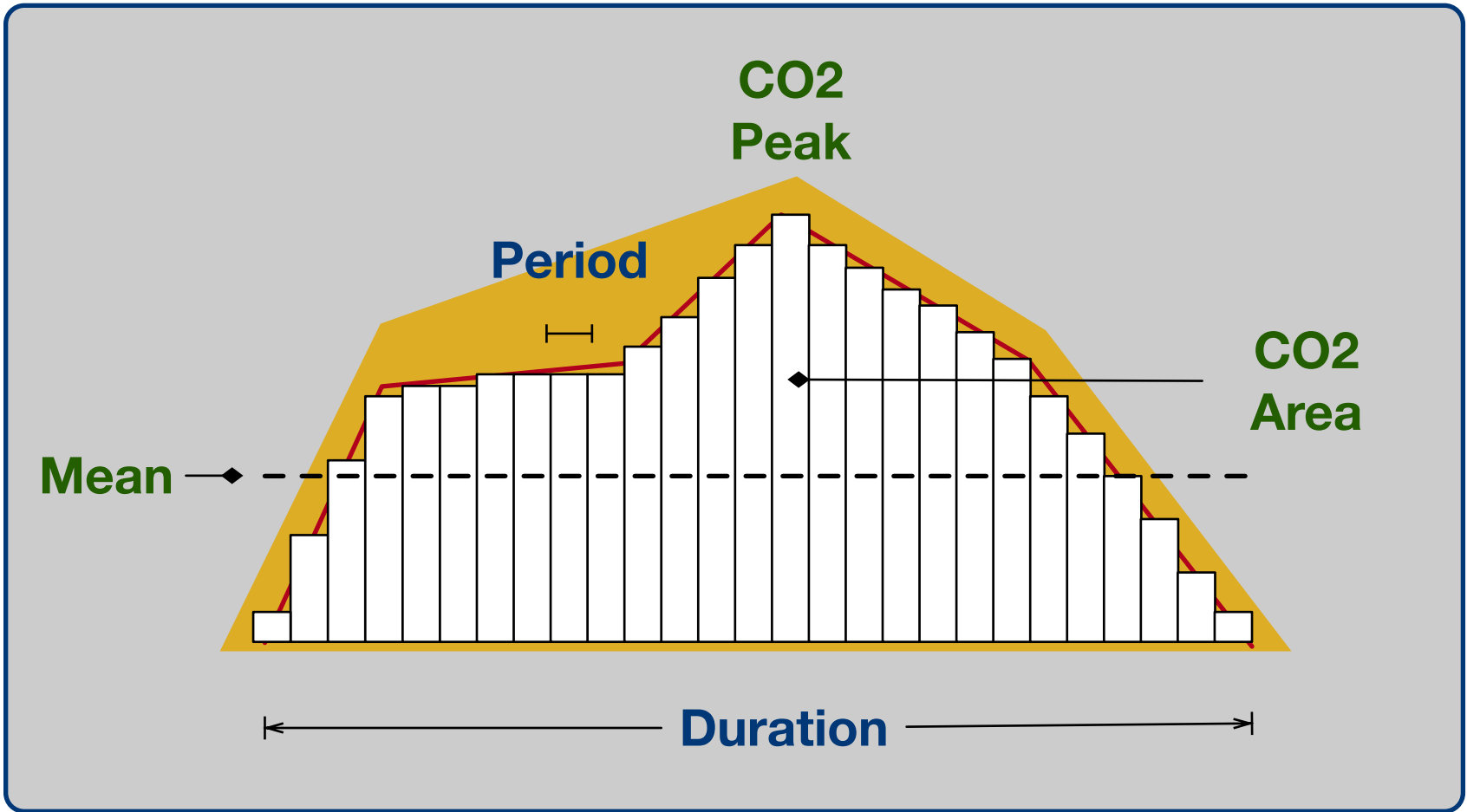
Averages of all parameters are taken for all conditions.

During the sample measurement, CO2 peak and area features are also measured.

[1] - Trapezoid method; $dA = dy \cdot dt = 0.5(y + y_o) \cdot (t - t_o)$

[2] - measured parameters
co2, co2abs, h2o, h2odp, celltemp, cellpres,
ivolt, flowrate, raw_co2, raw_co2ref, raw_h2o, raw_h2o_ref

[3] - average computed using Welford's method (single pass, i.e. uses only current, previous samples, reduces over/under flow)



Log Structure

DATyymm.LOG

licor measurement, calibration samples

timestamp	type	fields...	CRLF
-----------	------	-----------	------

```
2019-05-02T08:49:12Z,R,Z,0,3FFFFFF,8,8.453497e-01,1.305093e-02,-3.495046e-04,5.394967e-06,1.120606e+01,4.896278e-04,8.841268e+00,5.731668e-04,8.717278e-02,2.007264e-06,2.105246e+01,2.839897e-03,1.1
2019-05-02T08:49:18Z,R,S,0,3FFFFFF,8,8.891398e-01,2.744835e-02,-3.675563e-04,1.133208e-05,1.121109e+01,6.558900e-04,8.847525e+00,7.058359e-04,8.719429e-02,2.460473e-06,2.107103e+01,2.764259e-03,1.1
2019-05-02T08:49:23Z,R,A,0,3FFFFFF,5,9.592422e-01,9.107444e-03,-3.964901e-04,3.751769e-06,1.121623e+01,8.642814e-04,8.854718e+00,1.093234e-03,8.722152e-02,4.237782e-06,2.108585e+01,1.160358e-03,1.1
2019-05-02T08:49:26Z,B,M,0,10,1556786966500,9.310020e-01,1556786971000,9.717710e-01,0.930,0.989,0.968,0.023
2019-05-02T08:49:48Z,S,M,0,3FFFFFF,30,9.540361e-01,2.030799e-02,-3.942457e-04,8.379639e-06,1.123179e+01,4.155738e-03,8.874358e+00,5.291691e-03,8.729175e-02,1.939195e-05,2.113332e+01,1.130981e-02,11
2019-05-02T08:49:51Z,B,M,0,10,1556786991500,9.246020e-01,1556786996000,8.760600e-01,0.871,0.945,0.911,0.027
```

RAWyymm.LOG

raw licor samples

timestamp	licor_xml	CRLF
-----------	-----------	------

```
2019-05-02T08:46:21Z,<li850><data><celltemp>2.04872e1</celltemp><cellpres>1.01731e2</
cellpres><co2>-4.00649e1</co2><co2abs>1.7684102e-2</co2abs><h2o>7.50644</
h2o><h2oabs>6.5430402e-2</h2oabs><h2od
ewpoint>3.04880</h2odewpoint><ivolt>1.2276172e1</ivolt><raw><co2>4553910</
co2><co2ref>5034416</co2ref><h2o>2313719</h2o><h2oref>3949373</h2oref></raw><flowrate>0</
flowrate></data></li850>
```

SYSyymm.LOG

status information

timestamp	msg	CRLF
-----------	-----	------

```
2019-05-20T08:37:57Z,nmeas.a streamx err[1]
2019-05-20T08:38:04Z,nmeas.a streamx err[1]
2019-05-20T08:38:09Z,nmeas.a streamx err[1]
2019-05-20T08:38:36Z,nmeas.a streamx err[1]
2019-05-20T08:38:44Z,set [BITS P* V*]
2019-05-20T08:38:45Z,set [BITS P* V* LI]
2019-05-20T08:42:43Z,set [BITS LI]
2019-05-20T08:42:49Z,or set err[1]
2019-05-20T08:42:50Z,set [BITS LI]
```

File Encoding
Record Format
Record Delimiter
Timestamp
File System
File Names
Segmentation
Indexed
Record IDs

ASCII, UTF-8
CSV
CRLF (0x0D0A)
ISO8601, Posix
FATFS
DOS (case insensitive, 8.3)
date, size (optional)
N
Self-identifying