Operations and Management of Large Environmental Monitoring Networks

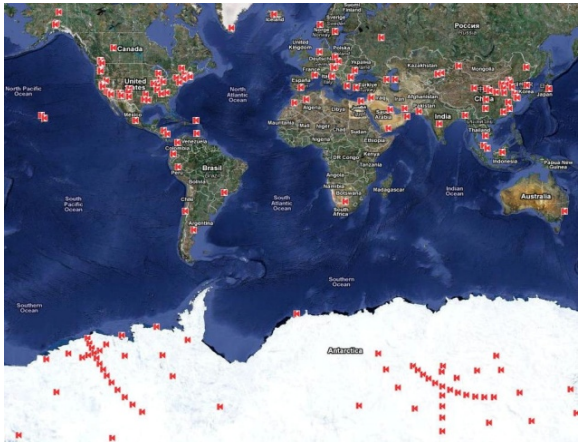
Danny Harvey

Boulder Real Time technologies

INTRODUCTION - KMI

Kinemetrics, Inc.

- Founded in 1969
- OYO Corp owned in 1991
- ISO9001 since 1999
- $35M FY2012 revenue (mostly international)



HQ's in Pasadena CA with Sales and Project offices in Switzerland & Abu Dhabi

INTRODUCTION – KMI TEAM

KINEMETRICS

Designs and manufactures sensors and digitizers – Provides complete systems design, installation and operations

QUANTERRA®

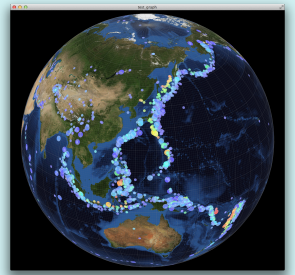
Designs High-End Digitizers

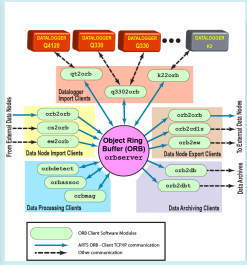
metrozet

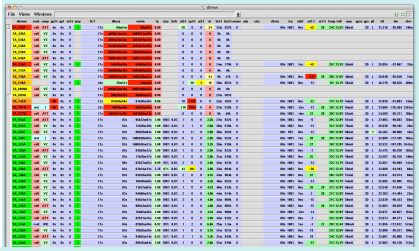
Designs High-End Sensors

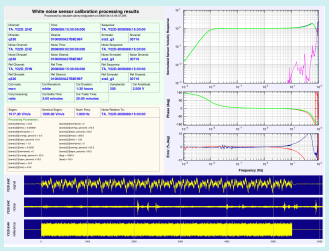
BRTT

Antelope Software









Environmental Monitoring Networks

- Seismic (ground vibration)
- Meteorological
- High resolution atmospheric pressure
- Infrasound
- GPS
- Hydroacoustic
- Radionuclide
- Chemical
- Image
- Etc.

Environmental Monitoring (EM) Network O&M Requirements

- Operational requirements (end user):
  - Acquire data from remote sensors
  - Provide data to downstream users using appropriate formats and protocols
  - High data completeness
  - Minimum data latencies
  - High data quality
  - High reliability and resilience to single system component failures (HA)

- Maintenance requirements (operator):
  - Real-time comprehensive view of total system state of health (SOH)
    - Must extend to remote sensors
    - Must encompass telemetry
    - Supports rapid resolution of any and all problems
  - Ability to securely command remote sensors
    - Modify configurations
    - Mass recenters (seismic)
    - In-situ sensor calibrations (seismic)
  - Note range and scope of SOH/C&C (largely OOB)

SOH Parameters

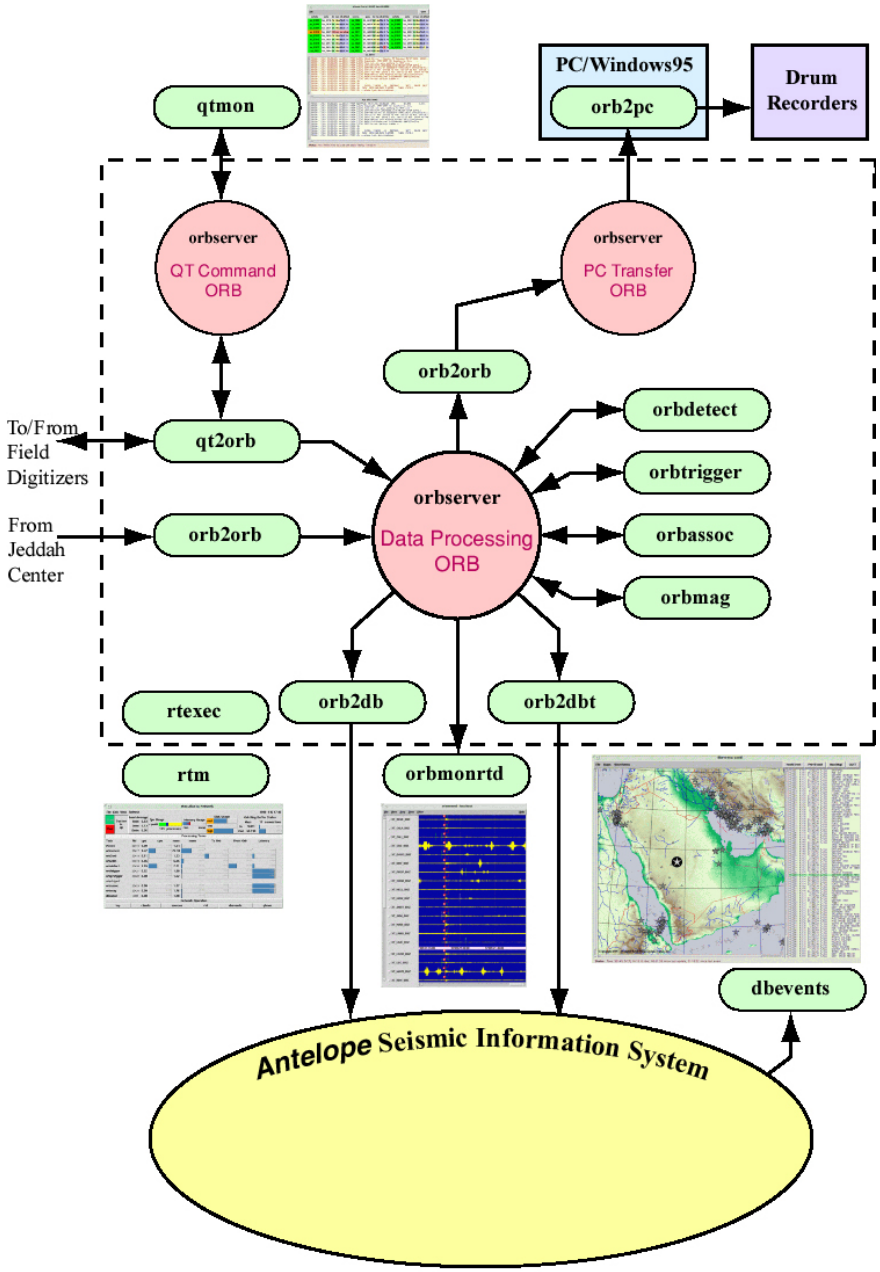
```
data_gps
data_gps_cs
data_cnp_err_port
data_cnp_err_code
data_slavep_err_code
data_dig_phase
data_dig_phase_why
data_backup
data_record
data_leap
data_pow_phase
data_anl_fault
data_cal_error
data_pll_drift
data_por_drift
data_sys_volt
data_sys_temp
data_sys_curr
data_ant_curr
data_spare_anl
data_status_port
data_opto_input
data_vco
data_pkt_buf
data_clk_qual
data_clk_pll
data_clk_ltc
```

```
data_clk_drift
data_clk_lcq
data_m0
data_m1
data_m2
data_m3
data_m4
data_m5
data_seis0_temp
data_seis1_temp
data_seis0_curr
data_seis1_curr
data_cal_abort
data_cal_status
data_suppl_pos
data_suppl_neg
data_masterfe_vco
data_masterfe_offset
data_slavefe_qual
data_slavefe_vco
data_slavefe_offset
data_batt_temp
data_batt_cap
data_batt_dd
data_batt_chg
data_batt_volt
data_bati_volt
data_batt_curr
```

```
q330_drate_tot
q330_throttle
q330_comm_eff
q330_data_gaps
q330_run_time
q330_data_ltc
q330_pkts_proc
q330_pkts_badsz
q330_pkts_chksm
q330_byts_rd24
q330_byts_wr24
q330_data_gp24
q330_data_gp1
q330_data_nl24
q330_data_nr24
q330_data_np24
q330_data_ni24
q330_data_tput
q330_data_bufr
```

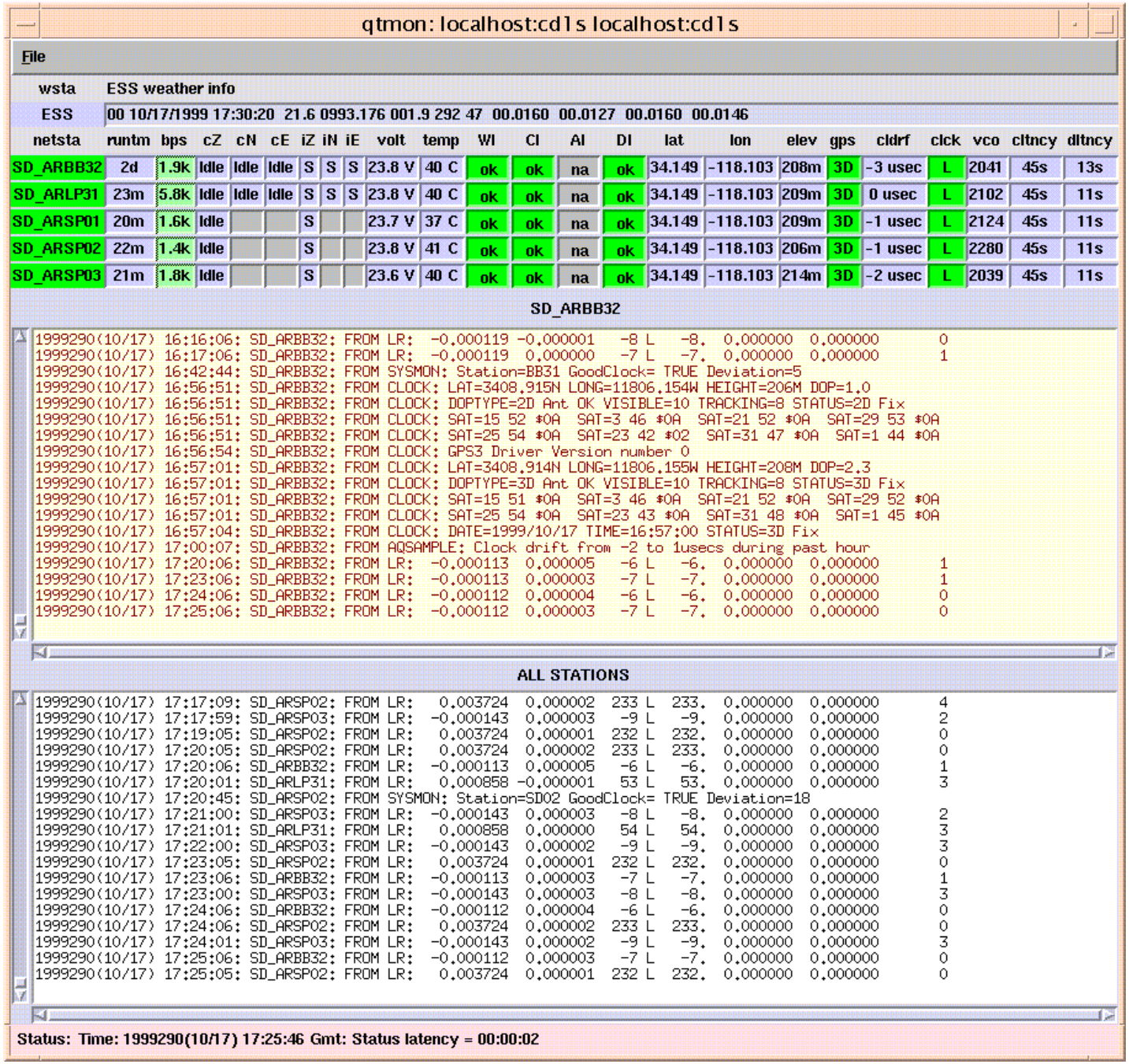
- 76 parameters for each station (64 being used by ANF for USArray)
- Waveforms as well as flags, states and alarms
- Produced at remote datalogger as well as at data acquisition center

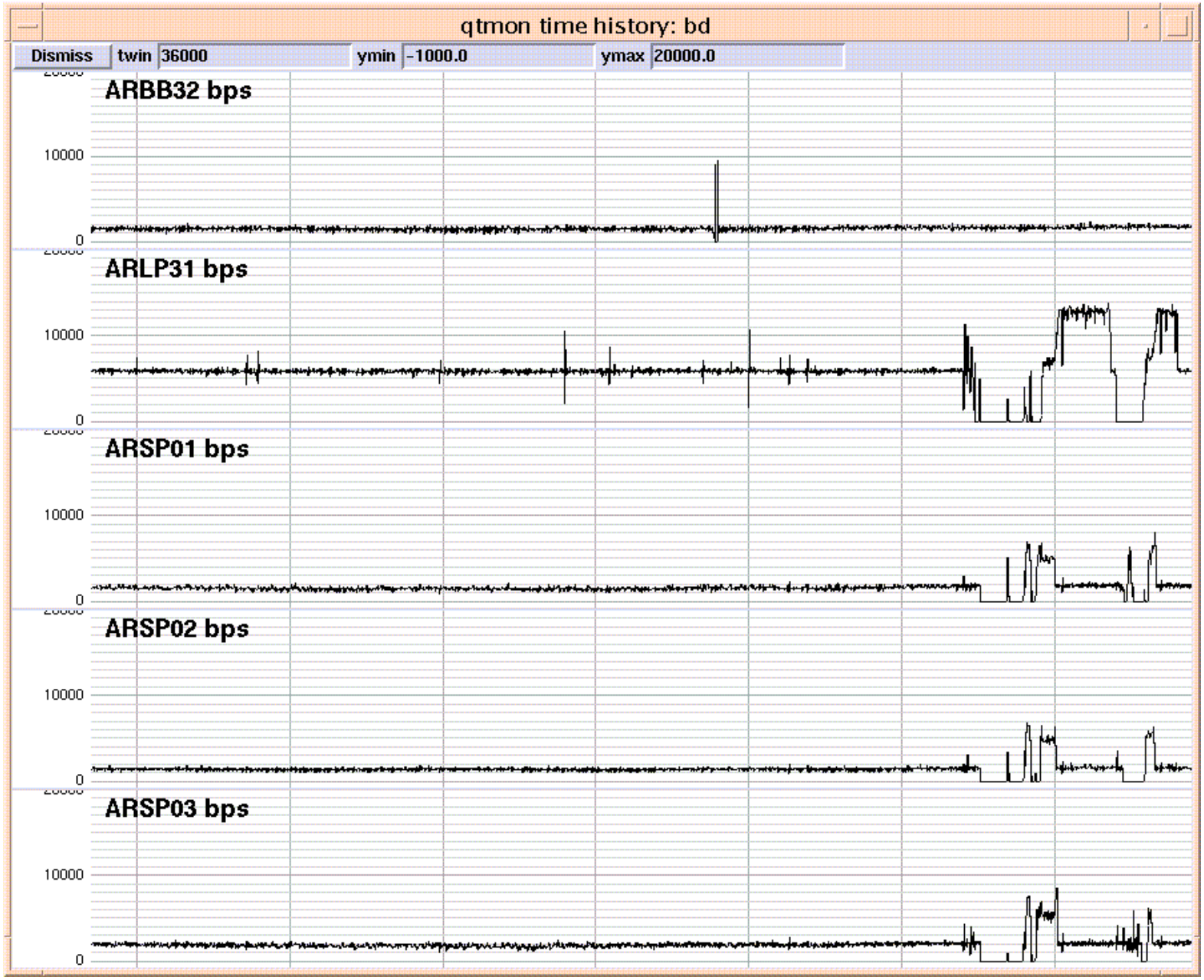
Saudi Arabia National Seismic Network 1997



SANSN SOH System

- Developed SOH data to encompass:
  - Time sampled waveform channels
  - Parametric time “snapshots”
  - Free form ASCII log messages
- Developed SOH GUIs
  - “Traffic light” displays
  - Log message displays
  - Waveform displays
  - Interaction for C&C

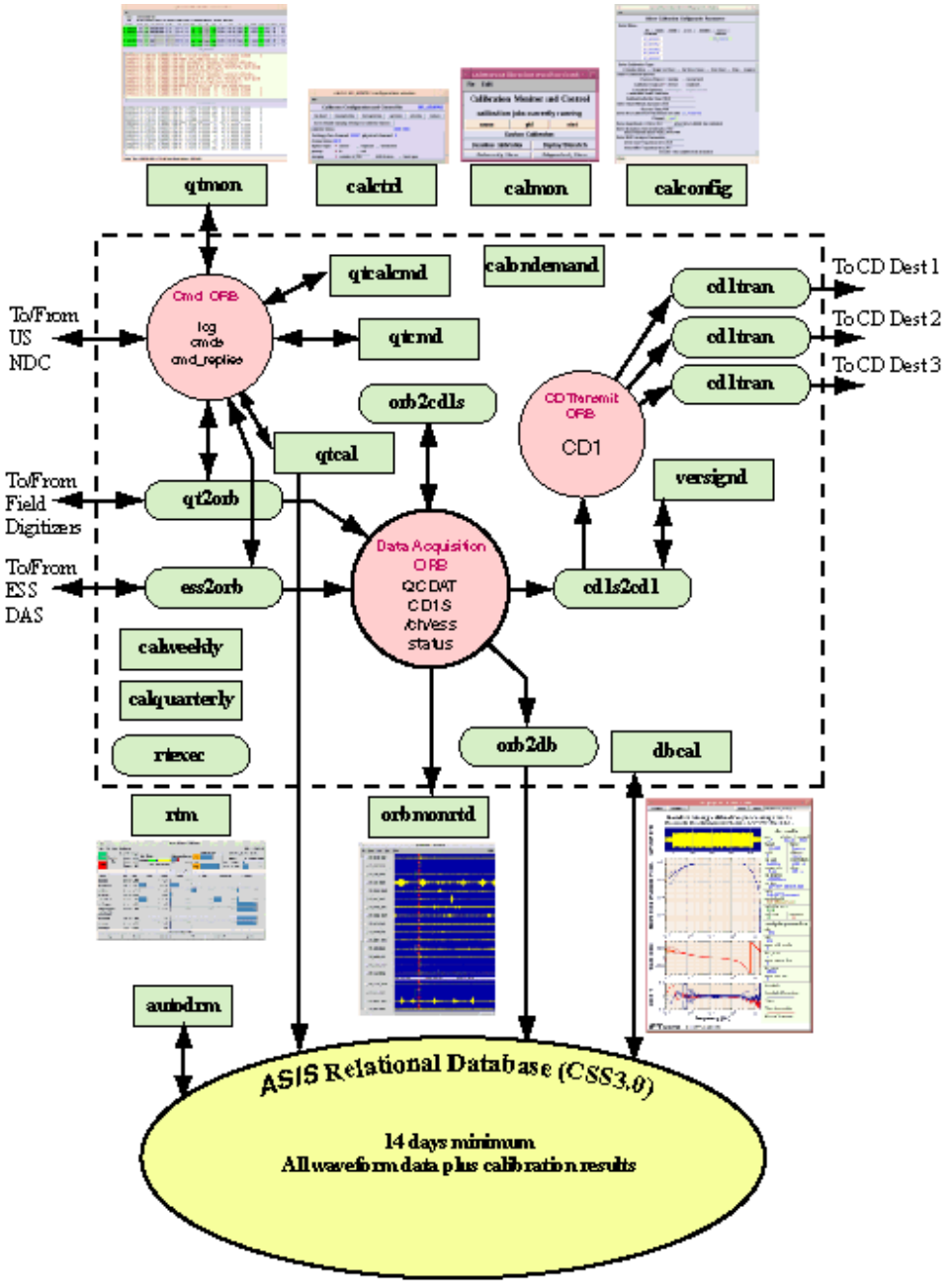

qtmon: localhost:cd1s localhost:cd1s
File
wsta ESS weather info
ESS 00 10/17/1999 17:30:20 21.6 0993.176 001.9 292 47 00.0160 00.0127 00.0160 00.0146
netsta runtm bps cZ cN cE iZ iN iE volt temp WI CI AI DI lat lon elev gps cldrf clck vco cltncy dltncy
SD_ARBB32 2d 1.9k Idle Idle Idle S S S 23.8 V 40 C ok ok na ok 34.149 -118.103 208m 3D -3 usec L 2041 45s 13s
SD_ARLP31 23m 5.8k Idle Idle Idle S S S 23.8 V 40 C ok ok na ok 34.149 -118.103 209m 3D 0 usec L 2102 45s 11s
SD_ARSP01 20m 1.6k Idle S 23.7 V 37 C ok ok na ok 34.149 -118.103 209m 3D -1 usec L 2124 45s 11s
SD_ARSP02 22m 1.4k Idle S 23.8 V 41 C ok ok na ok 34.149 -118.103 206m 3D -1 usec L 2280 45s 11s
SD_ARSP03 21m 1.8k Idle S 23.6 V 40 C ok ok na ok 34.149 -118.103 214m 3D -2 usec L 2039 45s 11s
SD_ARBB32
1999290(10/17) 16:16:06: SD_ARBB32: FROM LR: -0.000119 -0.000001 -8 L -8. 0.000000 0.000000 0
1999290(10/17) 16:17:06: SD_ARBB32: FROM LR: -0.000119 0.000000 -7 L -7. 0.000000 0.000000 1
1999290(10/17) 16:42:44: SD_ARBB32: FROM SYSMON: Station=BB31 GoodClock= TRUE Deviation=5
1999290(10/17) 16:56:51: SD_ARBB32: FROM CLOCK: LAT=3408.915N LONG=11806.154W HEIGHT=206M DOP=1.0
1999290(10/17) 16:56:51: SD_ARBB32: FROM CLOCK: DOPTYPE=2D Ant OK VISIBLE=10 TRACKING=8 STATUS=2D Fix
1999290(10/17) 16:56:51: SD_ARBB32: FROM CLOCK: SAT=15 52 $0A SAT=3 46 $0A SAT=21 52 $0A SAT=29 53 $0A
1999290(10/17) 16:56:51: SD_ARBB32: FROM CLOCK: SAT=25 54 $0A SAT=23 42 $02 SAT=31 47 $0A SAT=1 44 $0A
1999290(10/17) 16:56:54: SD_ARBB32: FROM CLOCK: GPS3 Driver Version number 0
1999290(10/17) 16:57:01: SD_ARBB32: FROM CLOCK: LAT=3408.914N LONG=11806.155W HEIGHT=208M DOP=2.3
1999290(10/17) 16:57:01: SD_ARBB32: FROM CLOCK: DOPTYPE=3D Ant OK VISIBLE=10 TRACKING=8 STATUS=3D Fix
1999290(10/17) 16:57:01: SD_ARBB32: FROM CLOCK: SAT=15 51 $0A SAT=3 46 $0A SAT=21 52 $0A SAT=29 52 $0A
1999290(10/17) 16:57:01: SD_ARBB32: FROM CLOCK: SAT=25 54 $0A SAT=23 43 $0A SAT=31 48 $0A SAT=1 45 $0A
1999290(10/17) 16:57:04: SD_ARBB32: FROM CLOCK: DATE=1999/10/17 TIME=16:57:00 STATUS=3D Fix
1999290(10/17) 17:00:07: SD_ARBB32: FROM AQSAMPLE: Clock drift from -2 to 1usecs during past hour
1999290(10/17) 17:20:06: SD_ARBB32: FROM LR: -0.000113 0.000005 -6 L -6. 0.000000 0.000000 1
1999290(10/17) 17:23:06: SD_ARBB32: FROM LR: -0.000113 0.000003 -7 L -7. 0.000000 0.000000 1
1999290(10/17) 17:24:06: SD_ARBB32: FROM LR: -0.000112 0.000004 -6 L -6. 0.000000 0.000000 0
1999290(10/17) 17:25:06: SD_ARBB32: FROM LR: -0.000112 0.000003 -7 L -7. 0.000000 0.000000 0
ALL STATIONS
1999290(10/17) 17:17:09: SD_ARSP02: FROM LR: 0.003724 0.000002 233 L 233. 0.000000 0.000000 4
1999290(10/17) 17:17:59: SD_ARSP03: FROM LR: -0.000143 0.000003 -9 L -9. 0.000000 0.000000 2
1999290(10/17) 17:19:05: SD_ARSP02: FROM LR: 0.003724 0.000001 232 L 232. 0.000000 0.000000 0
1999290(10/17) 17:20:05: SD_ARSP02: FROM LR: 0.003724 0.000002 233 L 233. 0.000000 0.000000 0
1999290(10/17) 17:20:06: SD_ARBB32: FROM LR: -0.000113 0.000005 -6 L -6. 0.000000 0.000000 1
1999290(10/17) 17:20:01: SD_ARLP31: FROM LR: 0.000858 -0.000001 53 L 53. 0.000000 0.000000 3
1999290(10/17) 17:20:45: SD_ARSP02: FROM SYSMON: Station=SD02 GoodClock= TRUE Deviation=18
1999290(10/17) 17:21:00: SD_ARSP03: FROM LR: -0.000143 0.000003 -8 L -8. 0.000000 0.000000 2
1999290(10/17) 17:21:01: SD_ARLP31: FROM LR: 0.000858 0.000000 54 L 54. 0.000000 0.000000 3
1999290(10/17) 17:22:00: SD_ARSP03: FROM LR: -0.000143 0.000002 -9 L -9. 0.000000 0.000000 3
1999290(10/17) 17:23:05: SD_ARSP02: FROM LR: 0.003724 0.000001 232 L 232. 0.000000 0.000000 0
1999290(10/17) 17:23:06: SD_ARBB32: FROM LR: -0.000113 0.000003 -7 L -7. 0.000000 0.000000 1
1999290(10/17) 17:23:00: SD_ARSP03: FROM LR: -0.000143 0.000003 -8 L -8. 0.000000 0.000000 3
1999290(10/17) 17:24:06: SD_ARBB32: FROM LR: -0.000112 0.000004 -6 L -6. 0.000000 0.000000 0
1999290(10/17) 17:24:06: SD_ARSP02: FROM LR: 0.003724 0.000002 233 L 233. 0.000000 0.000000 0
1999290(10/17) 17:24:01: SD_ARSP03: FROM LR: -0.000143 0.000002 -9 L -9. 0.000000 0.000000 3
1999290(10/17) 17:25:06: SD_ARBB32: FROM LR: -0.000112 0.000003 -7 L -7. 0.000000 0.000000 0
1999290(10/17) 17:25:05: SD_ARSP02: FROM LR: 0.003724 0.000001 232 L 232. 0.000000 0.000000 0
Status: Time: 1999290(10/17) 17:25:46 Gmt: Status latency = 00:00:02


qtmon time history: bd
Dismiss
twin 36000
ymin -1000.0
ymax 20000.0
ARBB32 bps
10000
0
ARLP31 bps
10000
0
ARSP01 bps
10000
0
ARSP02 bps
10000
0
ARSP03 bps
10000
0

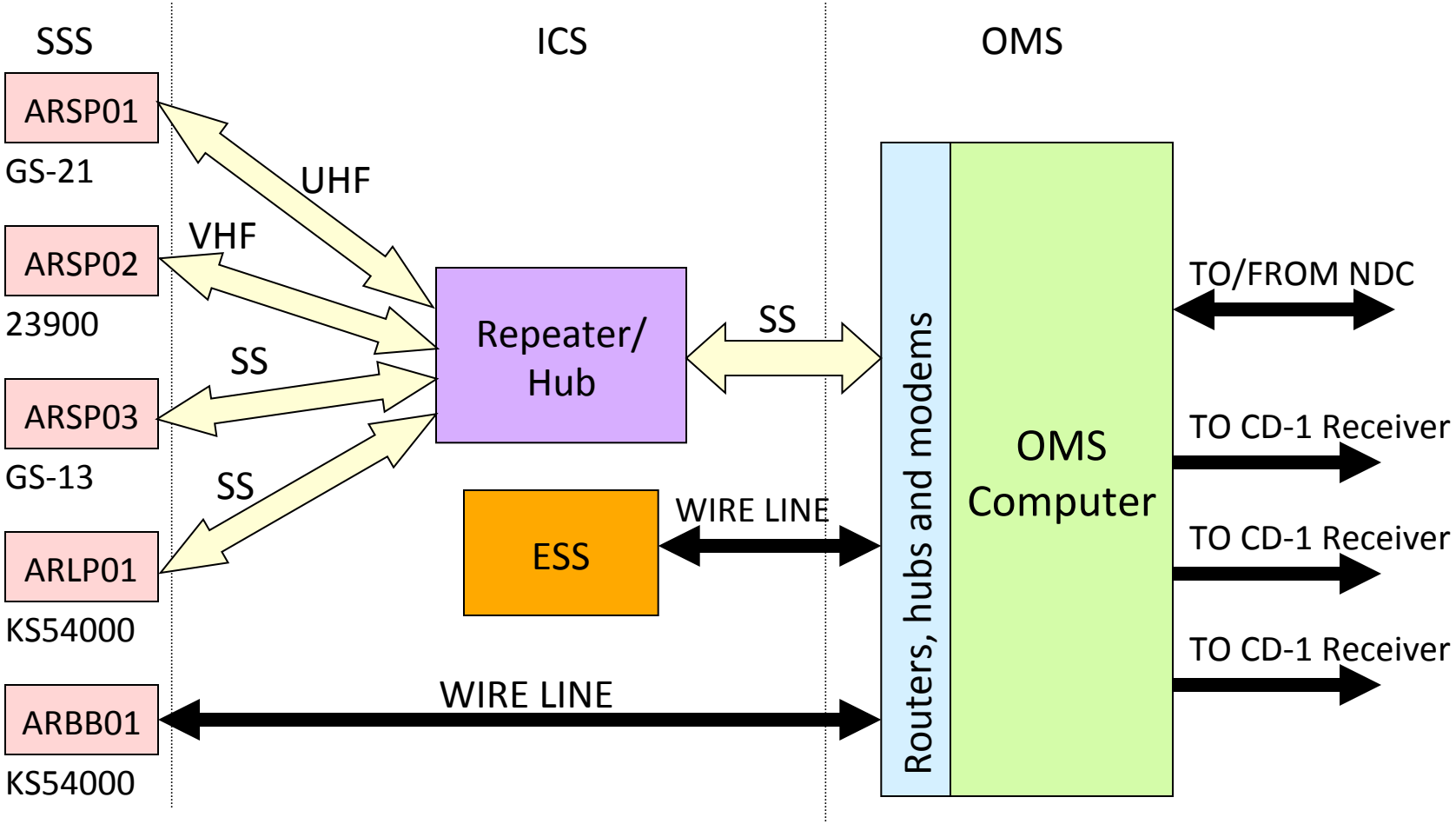
SANSN – Lessons Learned

- SOH encompasses a wide range of information types
- Proper displays can greatly increase operator effectiveness
- Comprehensive SOH information comes from both the remote sensors as well as the central acquisition software
- SOH information is not important for the end user or ultimate network mission

AFTAC/ SDAS/ Phase II 2000



SDAS Prototype Configuration



calconfig: calibration configuration window

File

Select Calibration Configuration Parameters

Select Sites:

All | None | 23900 | GS-21 | KS54000 | GS-13

Available	Selected
SD_ARSP01	SD_ARSP03
SD_ARSP02	
SD_ARSP03	
SD_ARLP31	
SD_ARBB32	

Select Calibration Type:

◆ Random Binary ◇ Single Sine Wave ◇ Sine Wave Sweep ◇ Free Period ◇ Step

Select Common Options:

Process Sites: ◆ Serially ◇ Concurrently

Calibrator Output: ◆ Sensor ◇ Loopback

Loopback Options: ☐ Preamp in ☐ Loopback loaded

Calibration Start Time: now

Calibration Settle Time: 130.0

Settle Time Without Autozero: 30.0

Recover Time: 10.0

Select rbc Calibration Parameters for Site SD_ARSP03

Channel: SHZ

Select Amplitude in Volts: 5.0 actual volts=5.00000 dac=0x6666,0

Select Duration Time in Minutes: 10.0

Select Random Seed Value: 0x123456

Select RBC Analysis Parameters:

Select Low Frequency in Hz: 0.01

Select Mid Frequency in Hz: 0.2

EXECUTE THE CALIBRATION SEQUENCE

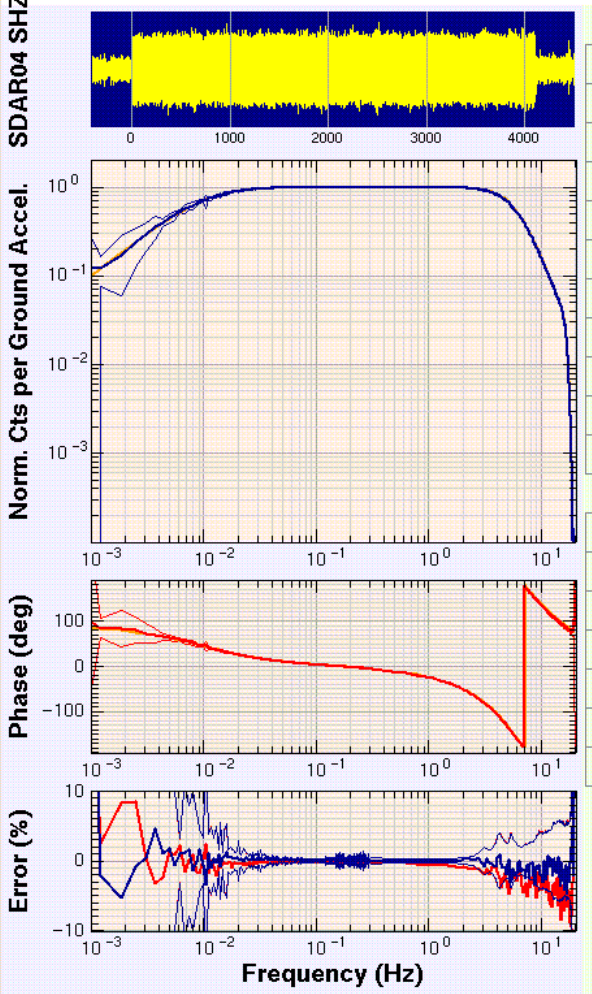
Status:

displaycal0 SDAR04 SHZ

Dismiss | Options... | print | save | displaycal_2269_0.ps

Random binary calibration processing results

Processed by dbcal:danny:ruper.brtt.com at 8/17/1999 20:27:52.751



rbc results

net:	station:	channel:
AF	SDAR04	SHZ

model: KS54000	manu: Geotech
serial: 0	cal input: sensor
cal seed: 0x123456	cal amplitude: 10.00 volt
sample rate: 40 sps	calper: 1.00 sec
cal duration: 4100.000 sec	
cal time: 8/17/1999 18:53:00.000	
calib: 0.00411799 nm/count	
nominal calib: 0.004026 nm/count	
calib difference: 2.3%	
calib cmp: ok	resp cmp: oor

analysis parameters

mlo: 4096
mhi: 256
force_total_stacks: 0
dec_factor: 4
apply_hipass_filter: 0
nhi_twins: 20000
apply_bias_cor: 0

Amplitude:

Amplitude Uncertainty:

Phase:

Phase Uncertainty:

Nominal Response:

BRTT Antelope 8/17/1999 20:28:07.000

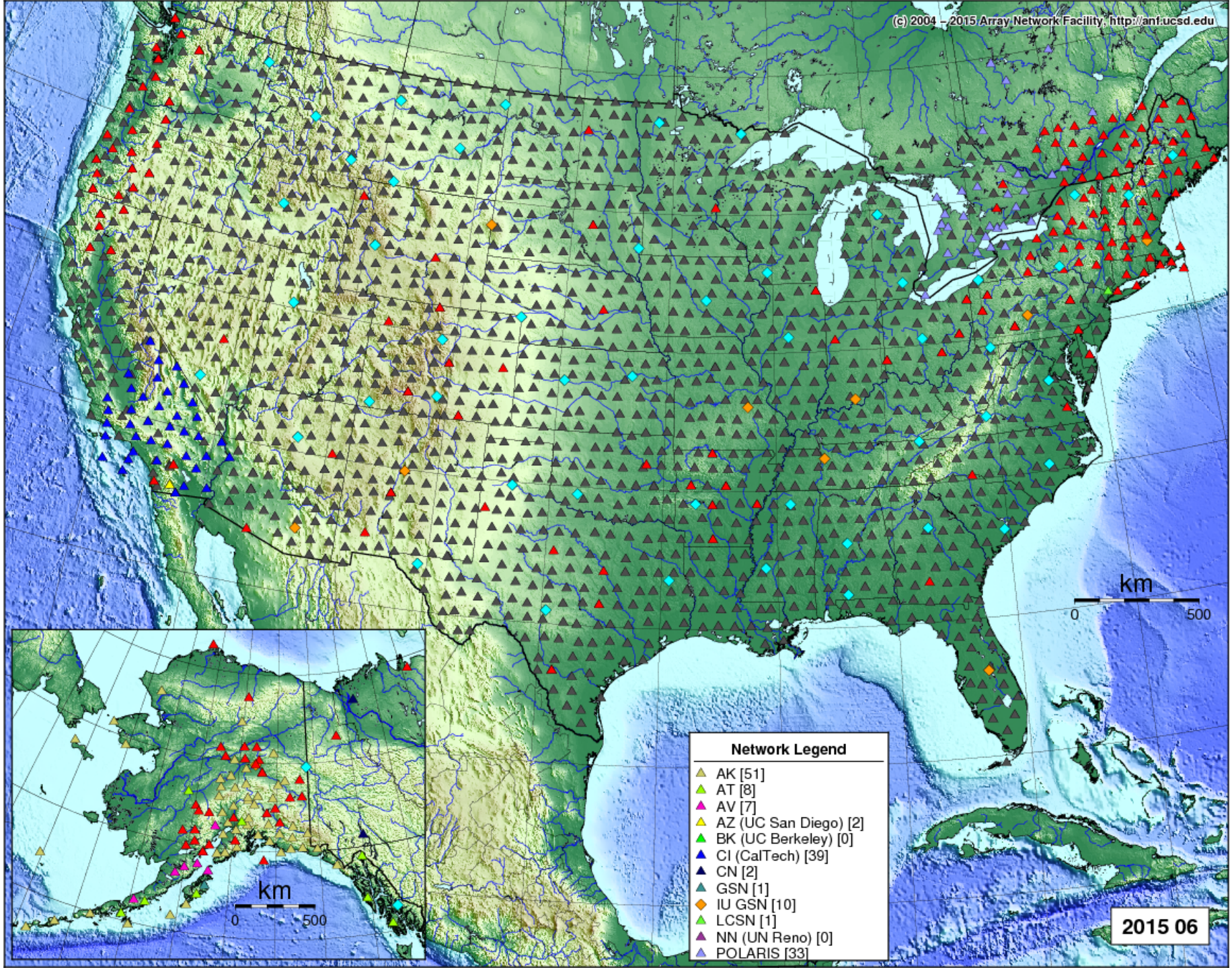
SDAS – Lessons Learned

- CD1 is not a suitable format for support of comprehensive SOH monitoring systems
- Even if we had been required to produce CD1 format out of the remote sites, we would have used different formats for SOH information and transmitted that information OOB with CD1 to implement a comprehensive SOH monitoring system
- The end users was not interested in most of the SOH information. The little bit of SOH information of interest to the end user was inserted into the CD1 data streams in special data blocks.

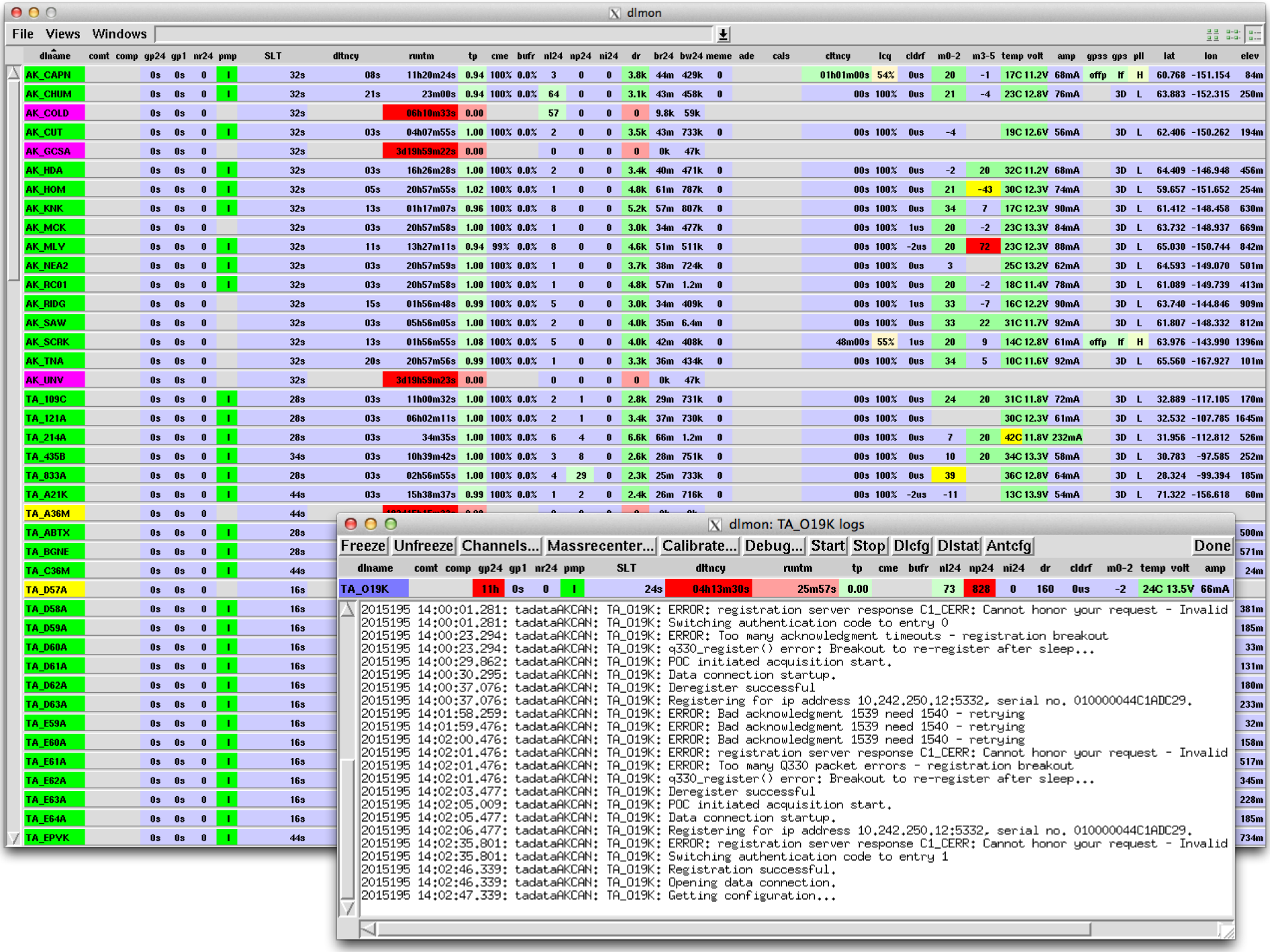
NSF/Earthscope/USArray

USArray – Lessons Learned

- Comprehensive SOH monitoring is the key to producing high quality data for large networks at a minimum cost
  - Over 2 years - 1166 dataloggers, 10,292 physical data channels at multiple sample rates, about 40,000 channels of SOH waveform data, 8760 instance-days of software running, 16 Terasamples of end user data (not including SOH)
  - 0 downtime, 0 lost data due to acquisition software failures over 2 years
  - 99.5% data completeness
  - 1 FTE to manage data center O&M


(c) 2004 – 2015 Array Network Facility, http://anf.ucsd.edu
km
0
500
km
0
500
Network Legend
AK [51]
AT [8]
AV [7]
AZ (UC San Diego) [2]
BK (UC Berkeley) [0]
CI (CalTech) [39]
CN [2]
GSN [1]
IU GSN [10]
LCSN [1]
NN (UN Reno) [0]
POLARIS [33]
2015 06


displaystations


dlmon
File Views Windows
dlname comt comp gp24 gp1 nr24 pmp SLT dltncy runtm tp cme bufr nl24 np24 ni24 dr br24 bw24 meme ade cals cltncy lcq cldrf m0-2 m3-5 temp volt amp gpss gps pll lat lon elev
AK_CAPN 0s 0s 0 I 32s 08s 11h20m24s 0.94 100% 0.0% 3 0 0 3.8k 44m 429k 0 01h01m00s 54% 0us 20 -1 17C 11.2V 68mA offp lf H 60.768 -151.154 84m
AK_CHUM 0s 0s 0 I 32s 21s 23m00s 0.94 100% 0.0% 64 0 0 3.1k 43m 458k 0 00s 100% 0us 21 -4 23C 12.8V 76mA 3D L 63.883 -152.315 250m
AK_COLD 0s 0s 0 32s 06h10m33s 0.00 57 0 0 0 9.8k 59k
AK_CUT 0s 0s 0 I 32s 03s 04h07m55s 1.00 100% 0.0% 2 0 0 3.5k 43m 733k 0 00s 100% 0us -4 19C 12.6V 56mA 3D L 62.406 -150.262 194m
AK_GCSA 0s 0s 0 32s 3d19h59m22s 0.00 0 0 0 0 0k 47k
AK_HDA 0s 0s 0 I 32s 03s 16h26m28s 1.00 100% 0.0% 2 0 0 3.4k 40m 471k 0 00s 100% 0us -2 20 32C 11.2V 68mA 3D L 64.409 -146.948 456m
AK_HOM 0s 0s 0 I 32s 05s 20h57m55s 1.02 100% 0.0% 1 0 0 4.8k 61m 787k 0 00s 100% 0us 21 -43 30C 12.3V 74mA 3D L 59.657 -151.652 254m
AK_KNK 0s 0s 0 I 32s 13s 01h17m07s 0.96 100% 0.0% 8 0 0 5.2k 57m 807k 0 00s 100% 0us 34 7 17C 12.3V 90mA 3D L 61.412 -148.458 630m
AK_MCK 0s 0s 0 32s 03s 20h57m58s 1.00 100% 0.0% 1 0 0 3.0k 34m 477k 0 00s 100% 1us 20 -2 23C 13.3V 84mA 3D L 63.732 -148.937 669m
AK_MLY 0s 0s 0 I 32s 11s 13h27m11s 0.94 99% 0.0% 8 0 0 4.6k 51m 511k 0 00s 100% -2us 20 72 23C 12.3V 88mA 3D L 65.030 -150.744 842m
AK_NEA2 0s 0s 0 I 32s 03s 20h57m59s 1.00 100% 0.0% 1 0 0 3.7k 38m 724k 0 00s 100% 0us 3 25C 13.2V 62mA 3D L 64.593 -149.070 501m
AK_RC01 0s 0s 0 I 32s 03s 20h57m58s 1.00 100% 0.0% 1 0 0 4.8k 57m 1.2m 0 00s 100% 0us 20 -2 18C 11.4V 78mA 3D L 61.089 -149.739 413m
AK_RIDG 0s 0s 0 32s 15s 01h56m48s 0.99 100% 0.0% 5 0 0 3.0k 34m 409k 0 00s 100% 1us 33 -7 16C 12.2V 90mA 3D L 63.740 -144.846 909m
AK_SAW 0s 0s 0 32s 03s 05h56m05s 1.00 100% 0.0% 2 0 0 4.0k 35m 6.4m 0 00s 100% 0us 33 22 31C 11.7V 92mA 3D L 61.807 -148.332 812m
AK_SCRK 0s 0s 0 32s 13s 01h56m55s 1.08 100% 0.0% 5 0 0 4.0k 42m 408k 0 48m00s 55% 1us 20 9 14C 12.8V 61mA offp lf H 63.976 -143.990 1396m
AK_TNA 0s 0s 0 32s 20s 20h57m56s 0.99 100% 0.0% 1 0 0 3.3k 36m 434k 0 00s 100% 0us 34 5 10C 11.6V 92mA 3D L 65.560 -167.927 101m
AK_UNV 0s 0s 0 32s 3d19h59m23s 0.00 0 0 0 0 0k 47k
TA_109C 0s 0s 0 I 28s 03s 11h00m32s 1.00 100% 0.0% 2 1 0 2.8k 29m 731k 0 00s 100% 0us 24 20 31C 11.8V 72mA 3D L 32.889 -117.105 170m
TA_121A 0s 0s 0 I 28s 03s 06h02m11s 1.00 100% 0.0% 2 1 0 3.4k 37m 730k 0 00s 100% 0us 30C 12.3V 61mA 3D L 32.532 -107.785 1645m
TA_214A 0s 0s 0 I 28s 03s 34m35s 1.00 100% 0.0% 6 4 0 6.6k 66m 1.2m 0 00s 100% 0us 7 20 42C 11.8V 232mA 3D L 31.956 -112.812 526m
TA_435B 0s 0s 0 I 34s 03s 10h39m42s 1.00 100% 0.0% 3 8 0 2.6k 28m 751k 0 00s 100% 0us 10 20 34C 13.3V 58mA 3D L 30.783 -97.585 252m
TA_833A 0s 0s 0 I 28s 03s 02h56m55s 1.00 100% 0.0% 4 29 0 2.3k 25m 733k 0 00s 100% 0us 39 36C 12.8V 64mA 3D L 28.324 -99.394 185m
TA_A21K 0s 0s 0 I 44s 03s 15h38m37s 0.99 100% 0.0% 1 2 0 2.4k 26m 716k 0 00s 100% -2us -11 13C 13.9V 54mA 3D L 71.322 -156.618 60m
TA_A36M 0s 0s 0 44s
TA_ABTX 0s 0s 0 I 28s 500m
TA_BGNE 0s 0s 0 I 28s 571m
TA_C36M 0s 0s 0 I 44s 24m
TA_D57A 0s 0s 0 16s
TA_D58A 0s 0s 0 I 16s 381m
TA_D59A 0s 0s 0 I 16s 185m
TA_D60A 0s 0s 0 I 16s 33m
TA_D61A 0s 0s 0 I 16s 131m
TA_D62A 0s 0s 0 I 16s 180m
TA_D63A 0s 0s 0 I 16s 233m
TA_E59A 0s 0s 0 I 16s 32m
TA_E60A 0s 0s 0 I 16s 158m
TA_E61A 0s 0s 0 I 16s 517m
TA_E62A 0s 0s 0 I 16s 345m
TA_E63A 0s 0s 0 I 16s 228m
TA_E64A 0s 0s 0 I 16s 185m
TA_EPYK 0s 0s 0 I 44s 734m
dlmon: TA_O19K logs
Freeze Unfreeze Channels... Massrecenter... Calibrate... Debug... Start Stop Dlcfg Dlstat Antcfg Done
dlname comt comp gp24 gp1 nr24 pmp SLT dltncy runtm tp cme bufr nl24 np24 ni24 dr cldrf m0-2 temp volt amp
TA_O19K 11h 0s 0 I 24s 04h13m30s 25m57s 0.00 73 828 0 160 0us -2 24C 13.5V 66mA
2015195 14:00:01.281: tadataAKCAN: TA_O19K: ERROR: registration server response C1_CERR: Cannot honor your request - Invalid
2015195 14:00:01.281: tadataAKCAN: TA_O19K: Switching authentication code to entry 0
2015195 14:00:23.294: tadataAKCAN: TA_O19K: ERROR: Too many acknowledgment timeouts - registration breakout
2015195 14:00:23.294: tadataAKCAN: TA_O19K: q330_register() error: Breakout to re-register after sleep...
2015195 14:00:29.862: tadataAKCAN: TA_O19K: POC initiated acquisition start.
2015195 14:00:30.295: tadataAKCAN: TA_O19K: Data connection startup.
2015195 14:00:37.076: tadataAKCAN: TA_O19K: Deregister successful
2015195 14:00:37.076: tadataAKCAN: TA_O19K: Registering for ip address 10.242.250.12:5332, serial no. 010000044C1ADC29.
2015195 14:01:58.259: tadataAKCAN: TA_O19K: ERROR: Bad acknowledgment 1539 need 1540 - retrying
2015195 14:01:59.476: tadataAKCAN: TA_O19K: ERROR: Bad acknowledgment 1539 need 1540 - retrying
2015195 14:02:00.476: tadataAKCAN: TA_O19K: ERROR: Bad acknowledgment 1539 need 1540 - retrying
2015195 14:02:01.476: tadataAKCAN: TA_O19K: ERROR: registration server response C1_CERR: Cannot honor your request - Invalid
2015195 14:02:01.476: tadataAKCAN: TA_O19K: ERROR: Too many Q330 packet errors - registration breakout
2015195 14:02:01.476: tadataAKCAN: TA_O19K: q330_register() error: Breakout to re-register after sleep...
2015195 14:02:03.477: tadataAKCAN: TA_O19K: Deregister successful
2015195 14:02:05.009: tadataAKCAN: TA_O19K: POC initiated acquisition start.
2015195 14:02:05.477: tadataAKCAN: TA_O19K: Data connection startup.
2015195 14:02:06.477: tadataAKCAN: TA_O19K: Registering for ip address 10.242.250.12:5332, serial no. 010000044C1ADC29.
2015195 14:02:35.801: tadataAKCAN: TA_O19K: ERROR: registration server response C1_CERR: Cannot honor your request - Invalid
2015195 14:02:35.801: tadataAKCAN: TA_O19K: Switching authentication code to entry 1
2015195 14:02:46.339: tadataAKCAN: TA_O19K: Registration successful.
2015195 14:02:46.339: tadataAKCAN: TA_O19K: Opening data connection.
2015195 14:02:47.339: tadataAKCAN: TA_O19K: Getting configuration...