A Tale of Two RWISs*

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*apologies to C. Dickens

The Current State of RWIS

- RWIS has a poor reputation
  - Reliability
    - Data not always available
    - Observed conditions do not correlate with data
    - Public will ignore data if perceived unreliable
  - Accuracy
    - Maintenance will not use data if they don't trust it
    - No independent way to ensure data integrity
  - Lack of detailed understanding
    - Vendor considers the RWIS a proprietary technology
      - Unwilling to help in troubleshooting problems other than "hard" failures.

What is an RWIS?

- For this report, an RWIS is defined as a remote weather station as provided by SSI, Inc. Items that may be part of the system include:
  - RPU (Remote Processing Unit) ← concentrate here
    - includes Outpost as "slave" RPU
  - Surface sensors (pucks) ← and especially here
  - Sub-surface sensor
  - Air Temp / Relative Humidity sensor
  - Precipitation sensor
  - Wind speed / direction sensor
  - Visibility sensor

What can we do to improve the reputation of RWIS systems?

- Reliability
  - What is the root cause of failure/perceived failure?
    - Mechanical/electrical component failure
    - Configuration issues (calibration)
- Accuracy
  - Understand the underlying accuracy of sensors
  - Understand how the RPU affects the end result
- Detailed understanding of process
  - If SSI will not provide details, can we determine operational details via experimentation?

Why we undertook a detailed investigation of RWIS

- Icy Curve Warning System (ICWS)
  - RWIS data used to automatically activate warning signs
    - Signs should only be on when conditions exist that allow for the formation of ice.
      - Maintenance reported signs ON during cold, clear and dry conditions.
    - Public will ignore signs if perceived unreliable
      - Obvious safety implications
      - Public perception of department incompetence

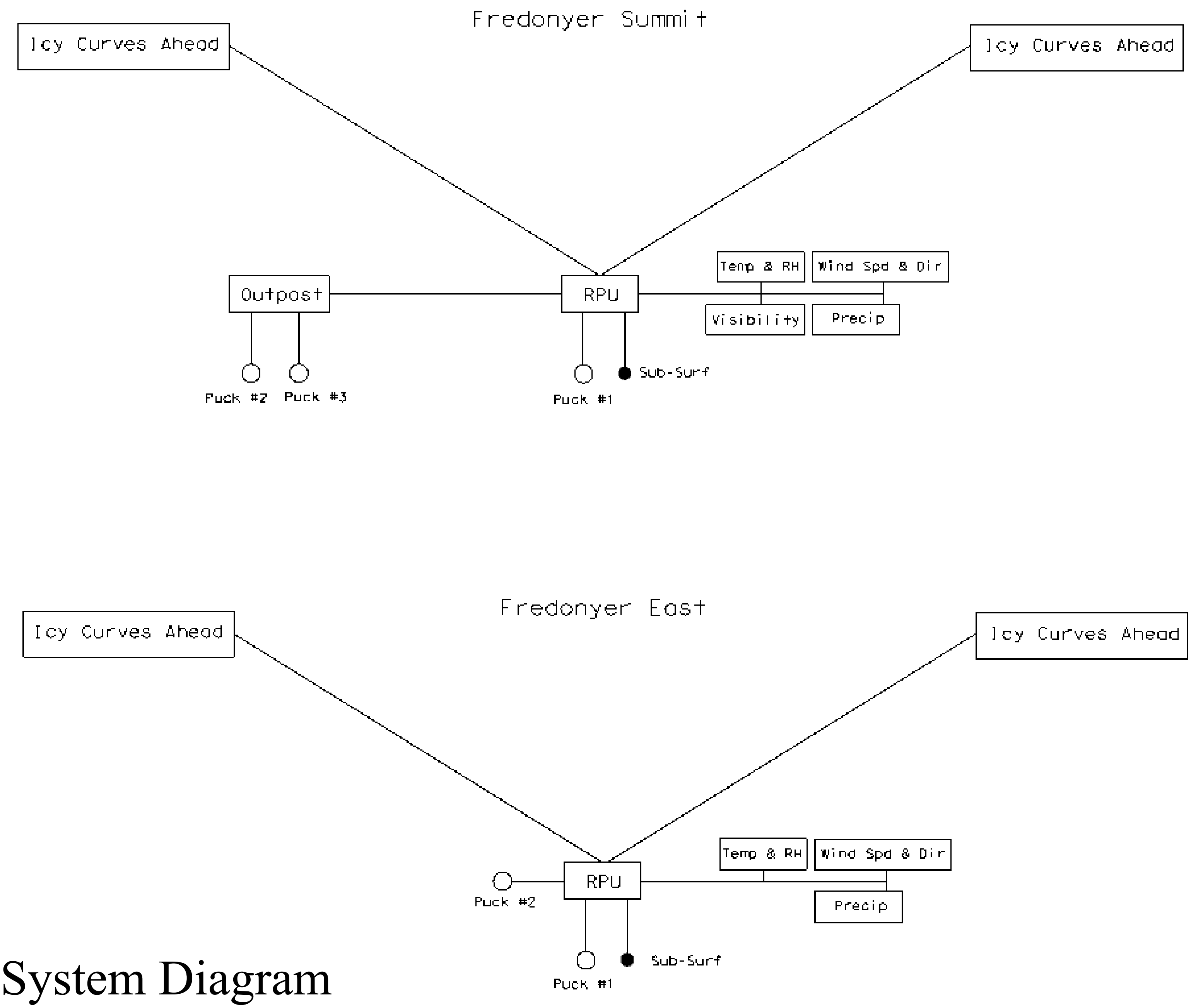

ICY CURVES
AHEAD
What is wrong with this picture?
10/19/2007 12:53

Initial assessment of system problems

- Limitations of the system
  - Proprietary algorithm used in the RPU to determine system status
  - Limited ability to use RPU data to make sign on/off decisions due to script language syntax
    - Not all data is presented to the script interface
- Is the problem sensing or processing?
  - Sensor accuracy (wet/dry/temp/raining/snowing etc.)
  - What does the RPU do with the data?

The Target Systems

- Two systems approximately 4 miles apart
  - Linux-based RPU
  - multiple surface sensors (pucks)
  - WIVIS™ (Weather Identifier Visibility Sensor) and standard precipitation sensor
  - Sub-surface sensors
  - Outpost
    - One system uses an "Outpost" to connect two of the pucks back to the RPU (1 mile)
    - This added additional unknowns to the data collection



System Diagram

Initial Observations

Initial Observations

- Both systems
  - Signs were on almost any time surface temp was < 32 F.
  - System reported the roadway was “wet” or “moist” on days with overcast but no precipitation.
  - “Dry” was only reported on days with significant sunlight.
- Differences
  - Summit puck #1 and both East pucks would show “Dry” much more often than Summit #2 and #3.
  - Summit #2 and #3 would stay “wet” for days, even without precipitation occurring.
- Control scripts turned on signs when status was “not dry” and surface temp < 32.4 F
  - Seemed reasonable, so what was not working?

Where to start?

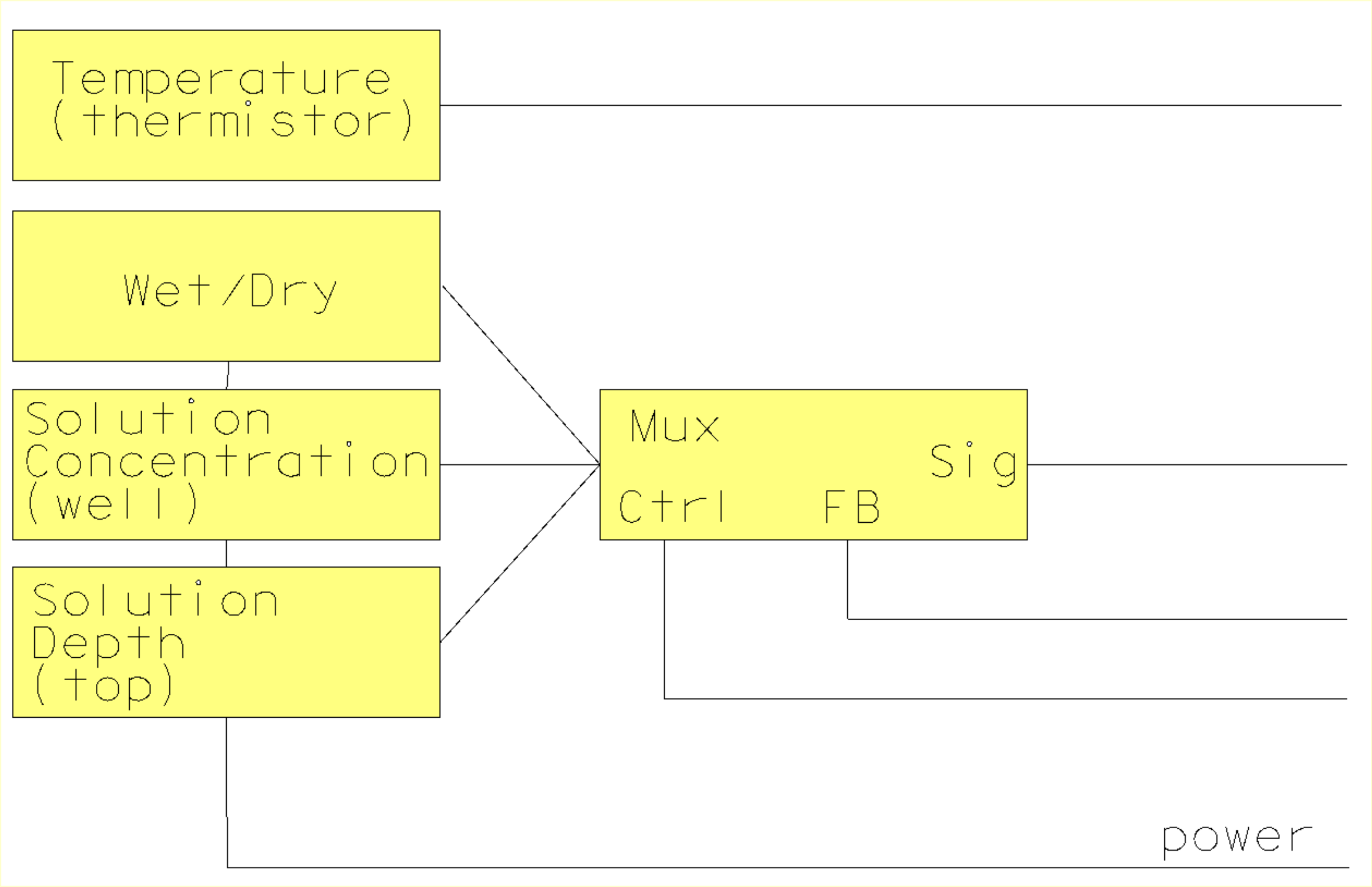
- Based on on-site observations and information from maintenance personnel:
  - "Surface Status" appeared to be the wild card in the data
    - The reported status did not agree with on-site observations, especially on cold, clear days
  - Even after "drying" the puck with a towel, system still reported "wet"
  - Pucks did report "dry" in some conditions
  - Needed a test procedure to confirm sensor operation


Find the dry puck………
1/23/2008 0:19

Puck details (FP2000)

- Four independent sections
  - Temperature sensor
  - Wet/dry sensor
  - Chemical concentration sensor
  - Moisture depth sensor
- Temp sensor is passive (thermistor)
  - Active at all times
- Output of three active sections is multiplexed onto a common signal line
  - Active sections are switched off between readings to minimize heating effect on sensor

FP2000 diagram



Temperature

- Thermistor based
  - Early models had 3 separate thermistors plus a “reference” resistor
  - Latest models have only one thermistor, ¼” below the puck surface
- Thermistor reacts quickly to external heat source
  - Temperature reading is sensitive to sun/shade conditions
    - When temp is near freezing, status is likely to alternate between freeze/no freeze
    - Need to introduce hysteresis if decisions are based on surface temp readings

Wet/dry sensor

- Based on “capacitance” measurement
  - Two oscillators (or 1 oscillator driven at two frequencies?)
    - ΔCapacitance → ΔFrequency → ΔVoltage
    - CH (Capacitance High) value uses 5 kHz
    - CL (Capacitance Low)value uses 100 Hz
  - As surface becomes moist, values of CH and CL increase
    - Raw values for early sensors are 0.7 to 0.9 volts dry, 0.95 to 1.2 volts wet.
    - Raw values for later sensors are 2.5 volts dry, 3.5 volts wet.
    - Raw values are scaled to 2.0 – 8.0 volts in RPU.
    - CH value is more sensitive to changes in moisture than CL

Wet/dry sensor (cont.)

- Scaled voltage level (which the RPU uses for decisions) depends on calibration values entered into RPU
  - Cal values are (apparently) the lowest raw dry value and the highest raw wet value.
  - Initial values are provided by SSI on the final test data sheet for each sensor.
  - These values will change with time (component drift)
  - Values can also change due to top surface wear
  - Formula (near as I can tell)

$$Scaled = 2.0 + \frac{Current - DryCal}{WetCal - DryCal} \times 6.0$$

Wet/dry sensor (cont.)

- If calibration value is too high/low compared to actual raw reading, scaled value will fall outside of 2.0 –8.0 volt window.
- RPU will report “error” or “no report” as the puck surface condition if scaled result is too far outside of window.

Surface Detail

Scaled voltage > 8.0

[main] [summary]

Sensor 1 EB SR 299

Surface Detail	Thu Mar 13 16:05:06 2008 UTC	6 seconds

Type	Sensor Type	Pavement Type	Elevation	Exposure
FP2000 Analog	Contact Passive	Asphalt	-10.00 m	80.00 %

Complete Set	Bad Mux Count	Bad Range Count	Sensor Sets	Incomplete Sets	Error
True	0	0	72987	0	None

T Ref Voltage	Temperature Voltage	Temperature
[illegible]	.0382 V	6.21 ° C / 43.18 ° F

is greater than this voltage

Resistance Calibration	
RWL Wet	0.4050 V
RTL Wet	0.5180 V

Resistance Readings	High	Medium	Low	Conductivity	C1 Scaled	Chemical Factor
Well (RW)	0.8011 V	7.9746 V	7.9746 V	0.046 mS	N/A	N/A
Top (RT)	7.9746 V	[illegible]	[illegible]	[illegible]	00	0.000

because this voltage

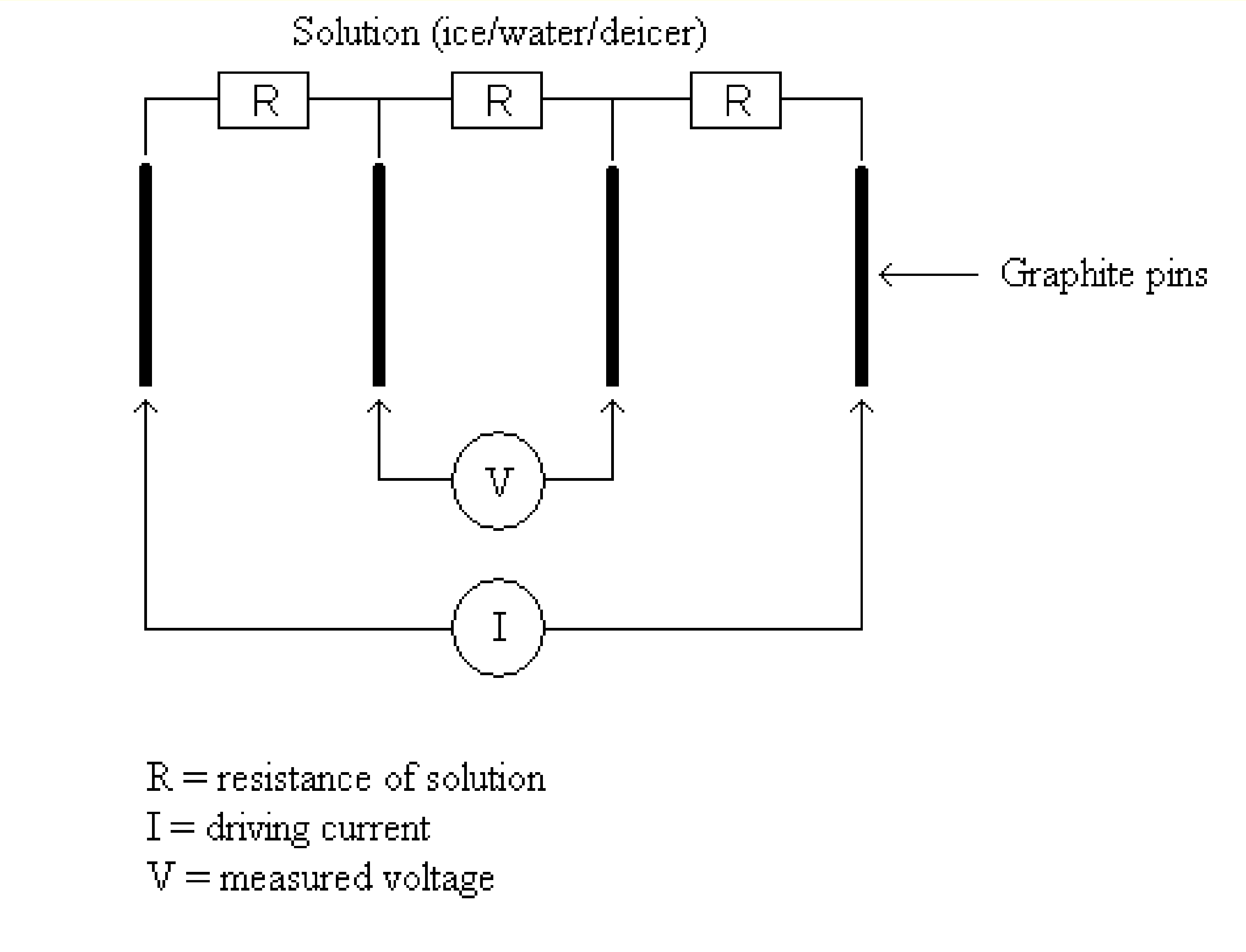
Capacitance Calibration	Dry	Wet
Low (CL)	2.1280 V	3.3248 V
High (CH)	2.1130 V	3.3687 V

Capacitance Readings	Minimum	Maximum	Current	Scaled
Low (CL)	2.2779 V	3.3512 V	3.3394 V	8.07
High (CH)	2.1054 V	3.3862 V	3.2166 V	7.27

Chemical Concentration/Solution Depth

- Both sensors use measurement of conductivity as the basic mechanism
  - Pass a current through a path and measure the developed voltage.
    - To increase dynamic range of measurement, use three different currents.
    - Start with highest current, reduce current as needed to provide a usable voltage (0.1<V<6.0).
    - Scale the resulting voltage depending on the cal values.
    - If source is unable to drive a particular current, set output to maximum (8.0 V)

Functional diagram of top/well sensors



Two sets of graphite pins in each sensor

- One set mounted flush with top surface
  - Measures solution depth
- One set mounted in a "well"
  - Captures solution to measure chemical concentration
    - Unaffected by depth other than "must be full"
    - Also reasonably tolerant of contaminants (cinders)
- Six measurements
  - (R)esistance
    - (W)ell or (T)op (location)
      - (H)igh, (M)edium, (L)ow (driving current)
  - RWH, RWM, RWL, RTH, RTM,RTL

Sensor pin location

Well/Top voltage display

Surface Detail

[main] [summary]

Sensor 2 LAS 036 011.05 EB

Surface Detail	Thu Mar 13 17:50:44 2008 UTC	56 seconds

Type	Sensor Type	Pavement Type	Elevation	Exposure
FP2000 Serial	Contact Passive	Asphalt	-300.00 m	100.00 %

Complete Set	Bad Mux Count	Bad Range Count	Sensor Sets	Incomplete Sets	Error
False	0	0	24	0	None

T Ref Voltage	Temperature Voltage	Temperature
0.0000 V	0.0000 V	7.92 ° C / 46.26 ° F

Resistance Calibration	
RWL Wet	0.3250 V
RTL Wet	0.4450 V

Resistance Readings	High	Medium	Low	Conductivity	C1 Scaled	Chemical Factor
Well (RW)	0.0230 V	1.0560 V	9.3390 V	.507 mS	N/A	N/A
Top (RT)	2.7540 V	8.6250 V	8.6280 V	.012 mS	0.000	35.000

Capacitance Calibration	Dry	Wet
Low (CL)	0.7000 V	1.0000 V
High (CH)	0.7000 V	1.0000 V

Capacitance Readings	Minimum	Maximum	Current	Scaled
Low (CL)	100.0000 V	-100.0000 V	0.0000 V	8.17
High (CH)	100.0000 V	-100.0000 V	0.0000 V	8.15

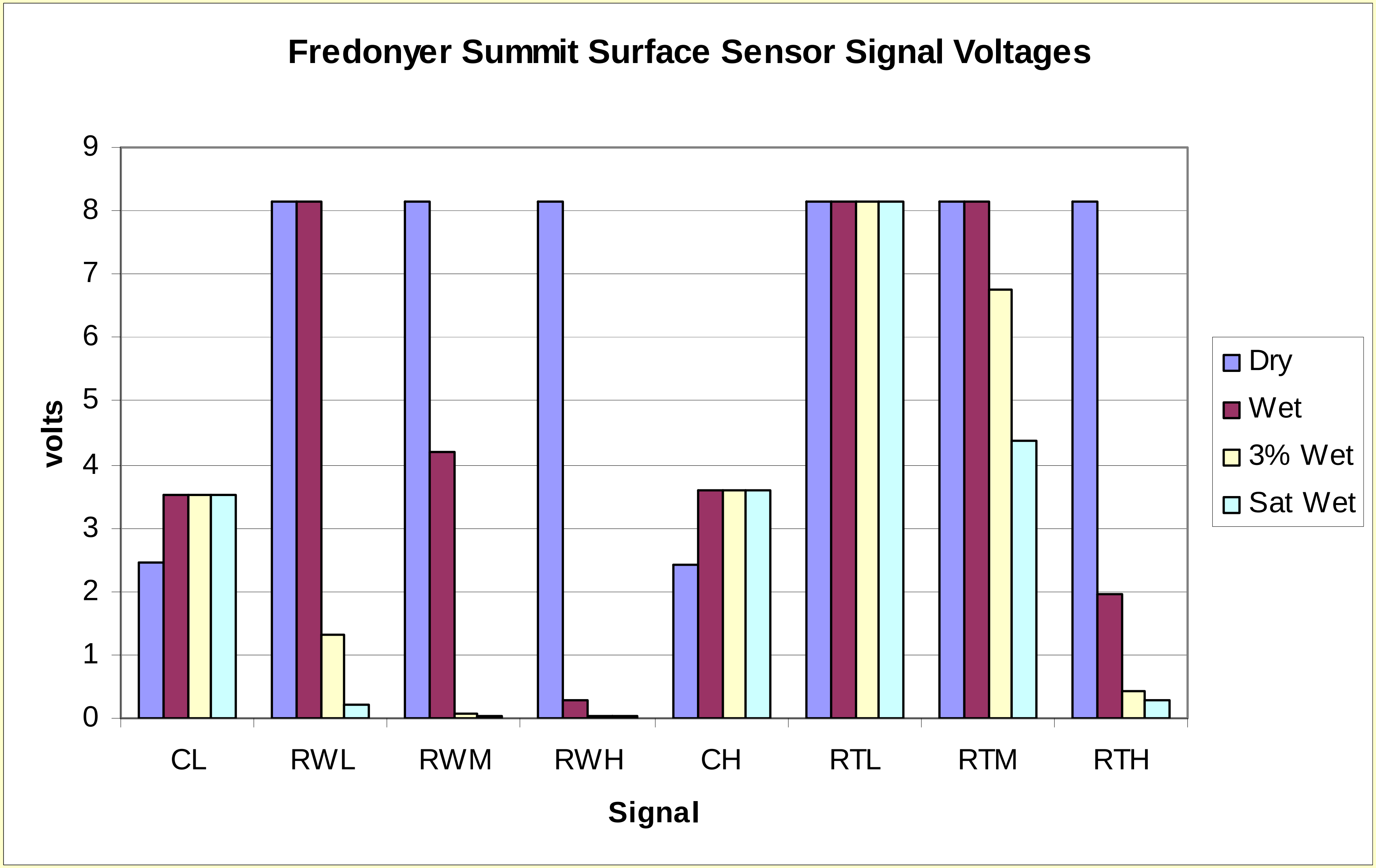
Experiments in sensor operation

- Measure all sensors at the RPU using the SSI recommended procedure
  - Needed to construct a test tool to control the internal mux and power the sensor separate from the RPU
- Record sensor voltages for 4 conditions:
  - Dry (cleaned thoroughly with Acetone)
  - Wet (plain water)
  - Wet, 3% NaCl solution
  - Wet, saturated NaCl solution
- Initial data seemed to point to a sensor problem
  - Sensor #1 checked out OK
  - Sensors #2 and #3 appeared to show “wet” at all times

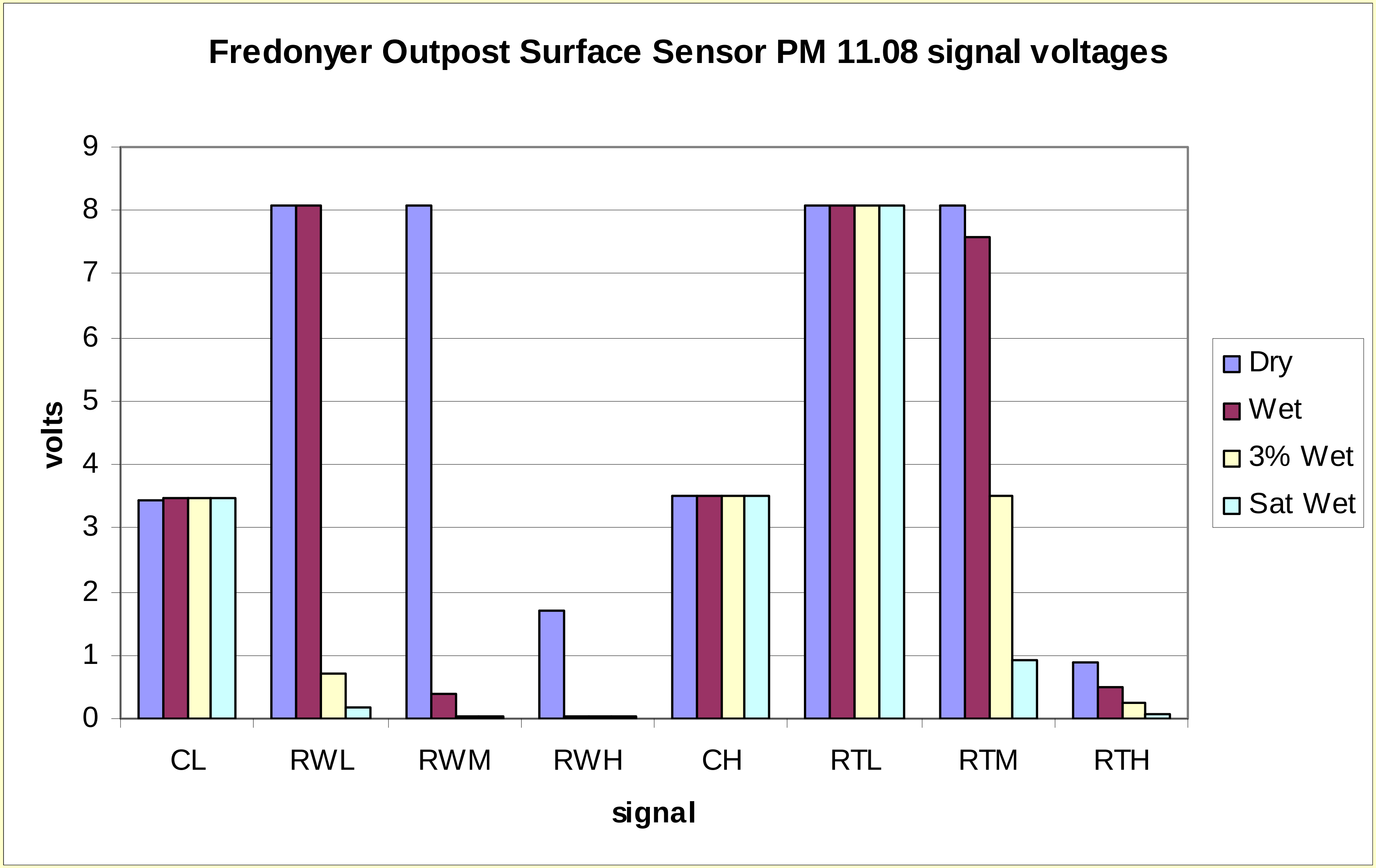
Experiments in sensor operation (cont)

Test tool v. 1.0

Experiments in sensor operation (cont)



Experiments in sensor operation (cont)



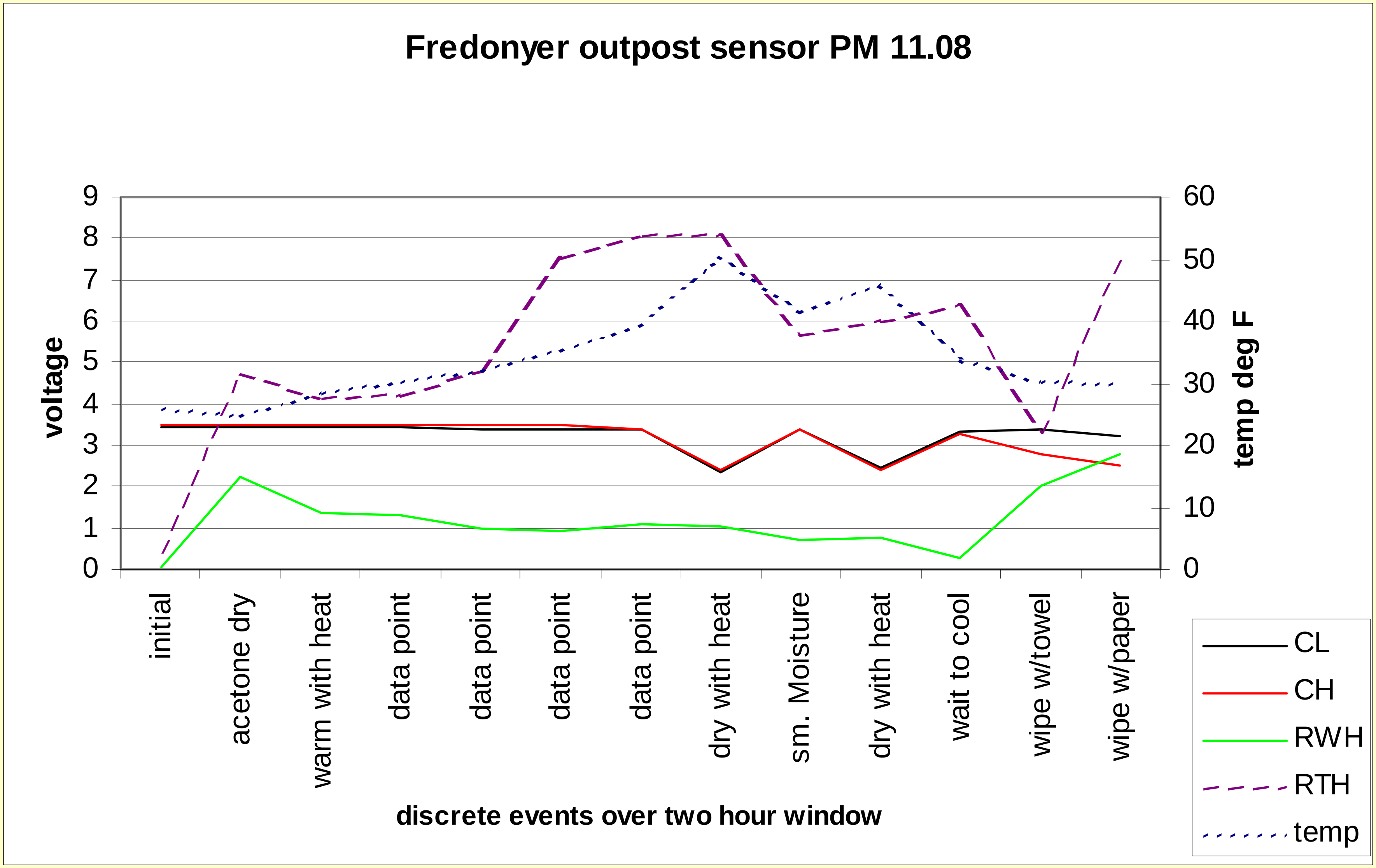
Experiments in sensor operation (cont)

- Consultation with SSI suggested that we had two bad sensors
  - This did not make sense since review of historical data showed that the sensors had reported dry conditions within recent months.
  - Using the test procedure at another site less than one year old yielded similar results
    - Something seemed to be wrong with the procedure or our understanding of how to accomplish it.

Experiments in sensor operation (cont)

- Test 2: isolate the sensor at the cable splice and take measurements
  - Advantage: able to watch sensor voltages as we made changes to the sensor conditions
    - Picked a cold day (20 F), overcast (typical day that had been giving false indications)
  - Tried to isolate what conditions were needed to get the sensor to indicate "dry"
  - Tried to determine what the wet/dry transition looked like in real time

Experiments in sensor operation (cont)



What did this prove?

- Conclusions
  - Sensor was working properly.
  - The problem was the definition of "dry"
    - Dry (to the sensor) means virtually all moisture evaporated from the surface
      - Wiping the sensor with a rag just put a nice, even film of moisture on the sensor.
      - Using more absorbent paper was better, but still left moisture trapped in the textured top surface

What did this prove? (cont)

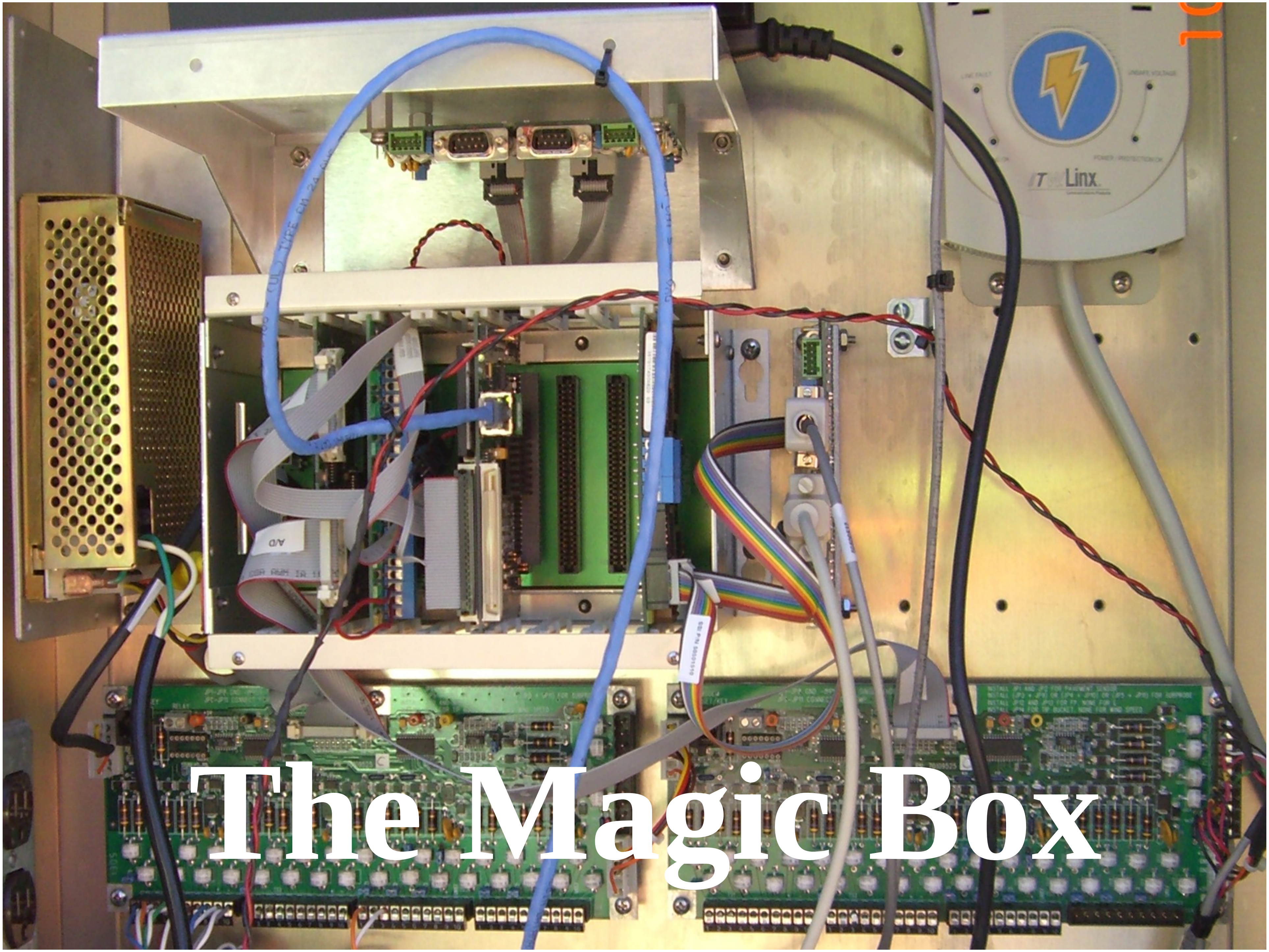
- When the sensor is cold, any moisture in the air tends to condense on the cold surface
- Even if the sensor was indicating “dry”, just having a vehicle run over it with a wet tire would drive it to “wet” or “trace moisture”
- Sensor appears to depend on direct heating (sunlight) to remove moisture to a level it considers “dry”
- Sensor appears to be more sensitive to small moisture changes when cold

What did this prove? (cont)

- Did any of this correlate with our earlier observations?
  - Sensor #1 tended to indicate “dry” more often than #2 & #3
    - Sensor #1 is located in an area that is much more open to the sky
  - Looking at historical data also confirmed that sensor #1 tended to be warmer at the same time of day than #2 & #3
    - Sensors 2 & 3 are in a heavily shaded area
  - We also observed snow blown from the trees onto the sensor was enough to change “dry” to “wet”

Sensor #1 location is open and in the clear


Sensors 2 & 3 are in a small canyon shrouded by trees
3/19/2008 11:44

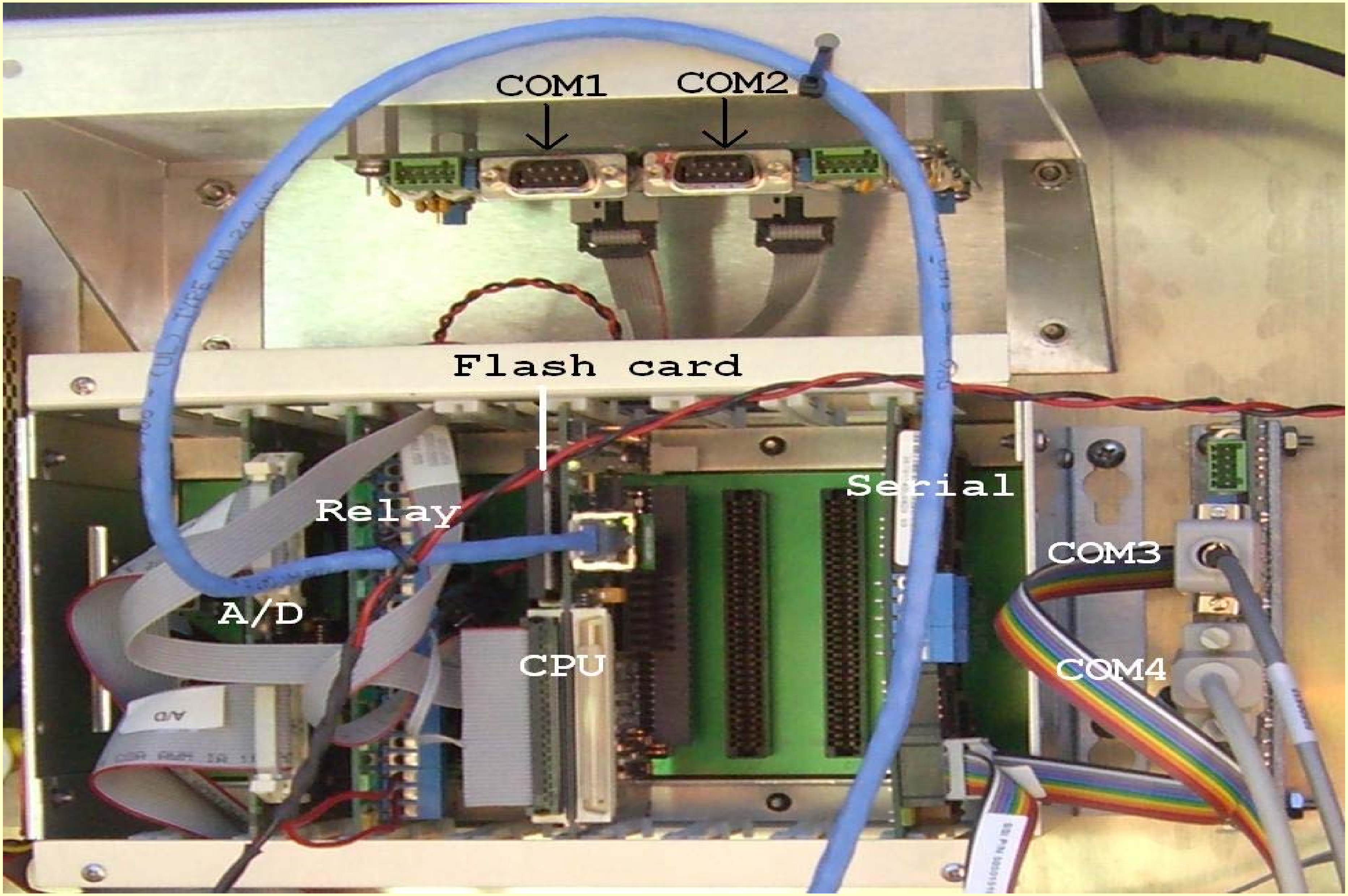


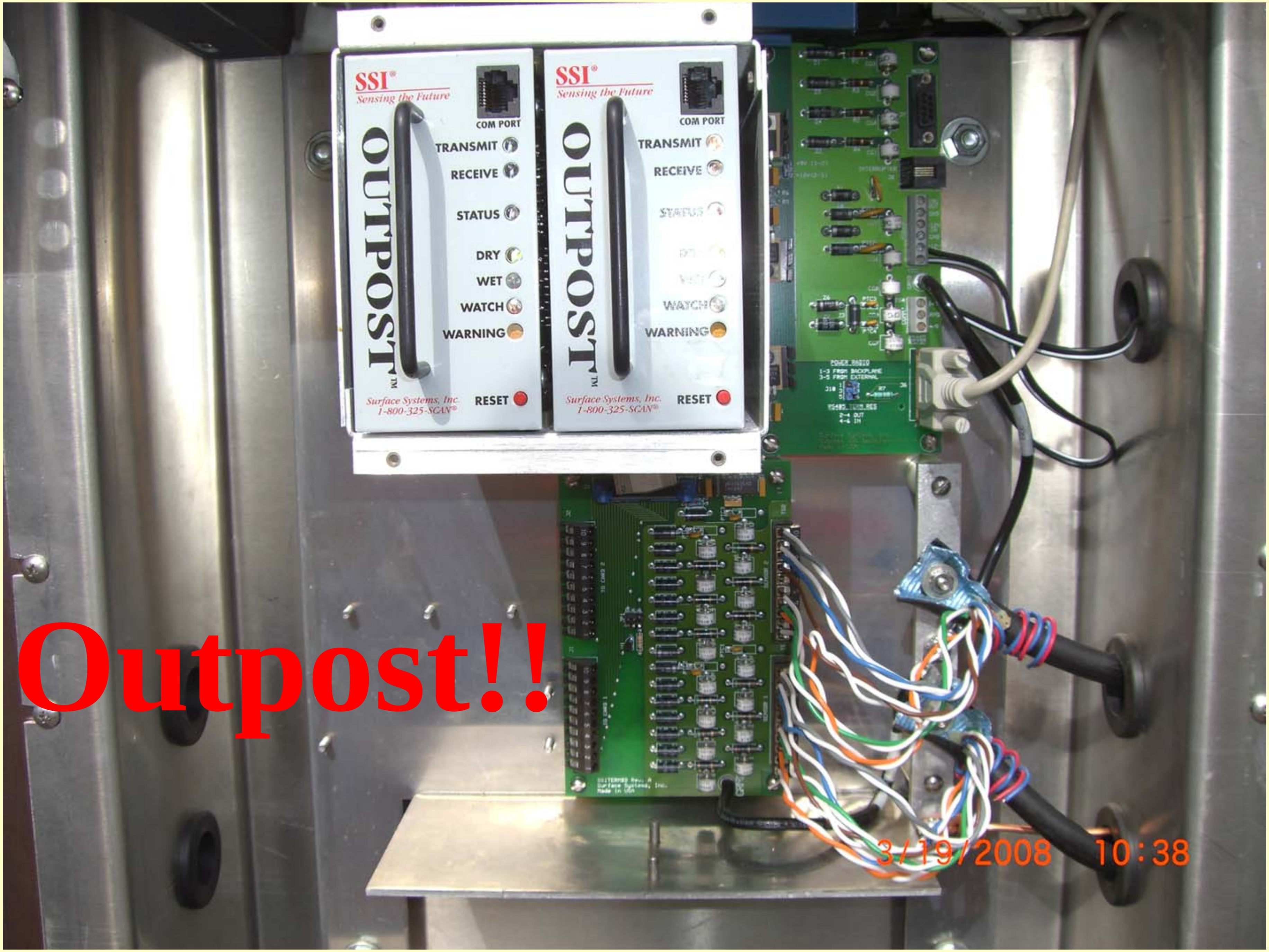
The Magic Box

The RPU Black Box

- Some details of the Linux-based RPU
  - Based on Octagon Systems 5070 CPU SBC (MicroPC format)
    - File system is 64 MB FLASH based except for two RAM based file systems for transient data.
  - COM1 provides console @ 38400-8-N-1
  - COM2 reserved for server connection
  - Other COM ports for WIVIS, Outpost provided by add-on board (octal serial board)
  - Analog to Digital input board is SSI product
  - OS is RedHat based Linux
    - uname = Linux localhost 2.4.18 i486

RPU parts identification




SSI
Sensing the Future
COM PORT
TRANSMIT
RECEIVE
STATUS
DRY
WET
WATCH
WARNING
OUTPOST
Surface Systems, Inc.
1-800-325-SCAN
RESET
Outpost!!
3/19/2008 10:38

Outpost details

- Outpost allows sensors to be placed remotely from RPU.
- Outpost does the Analog-to-Digital conversion that is normally done by the A/D board in the RPU
- Data is sent to the RPU via a serial link
- Physical link can be wired/wireless
- Calibration factors for pucks are in the Outpost
- Outpost can be accessed remotely over the same serial link using /scan/bin/sterm from RPU
  - Shuts down sensors while link is active.
  - Cryptic to use in practice
  - Similar interface to old DOS based RPU

Outpost details (cont)

- One advantage of the Outpost is that the RPU keeps a log of Outpost activity:

```
Mar 20 18:08:27 localhost sensord: OUTPOST: Port:4 Id:0x31 <0C1+QZ005E>

Mar 20 18:08:32 localhost sensord: OUTPOST: Port:4 Id:0x31<4E1+RZ00,13,0D6,2676,2676,267A,0D5,
2305,2305,2302,03FC,03FC,03FC,02F1,001855> Valid:Yes

Mar 20 18:08:32 localhost sensord: OUTPOST: Port:4 Id:0x32 <0C2+QZ005D>

Mar 20 18:08:36 localhost sensord: OUTPOST: Port:4 Id:0x32 <4E2+RZ00,10,0D2,2A7B,2A7F,2A7B,0D1,
2359,2356,2359,0510,0510,0519,8000,001B28> Valid:Yes
```

- Seems to capture about 12 hours for two sensors
- Cleared when RPU is restarted.
- Format is well documented (surprise!)

Outpost details (cont)

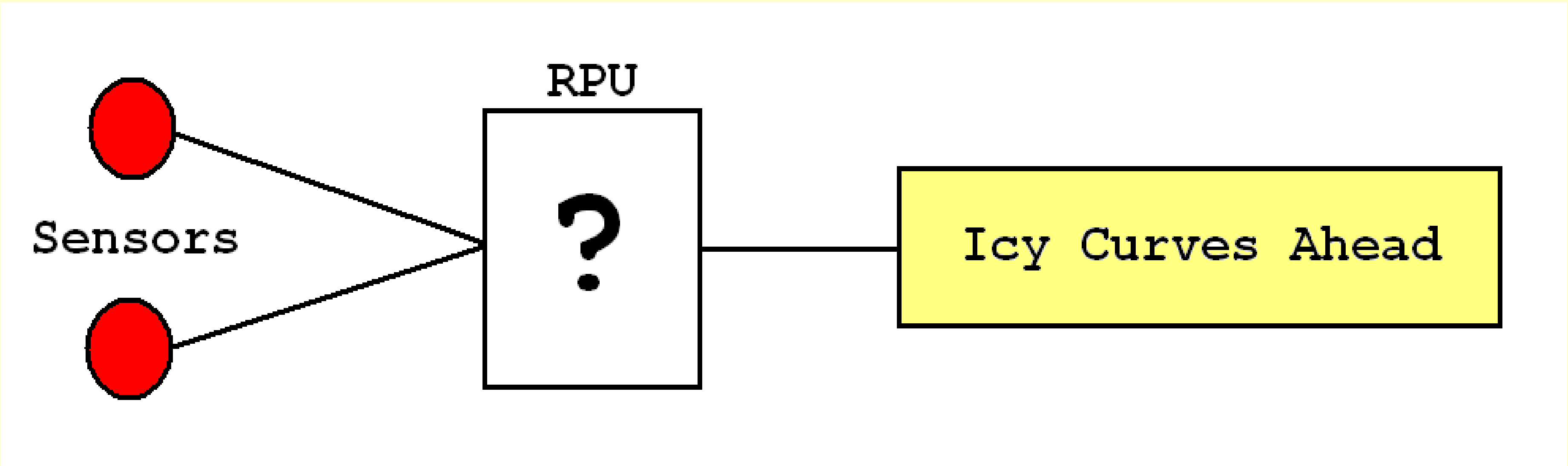
LX-RPU Maintenance Menu

LX-RPU Elite Model Version 1.16

Site	[configure] [remove log archive] [download log archive]
Configuration File	[backup] [restore] [download]
Time	[configure] [display]
Network	[configure] [ppp accounts] [route table] [display] [ppplog]
Snmp Daemon	[configure]
I/O Boards	[count] [summary] [ad status] [ad1 log] [ad2 log] [serial]
AC Power Monitor	[configure] [display]
Atmospherics	[summary] [display] [wivis/pwd log] [visibility relay log]
Surface	[count] [summary] [algorithm parameters] [outpost log] [display]
SubSurface	[count] [summary] [outpost log] [display]

The RPU Black Box

Now that we understand the sensor output, what is the RPU doing with/to it?



How the RPU decides what the sensor voltages mean in the real world (I think)

- RPU has algorithms that use the voltage inputs to provide outputs such as status (wet/damp/trace moisture/dry), solution depth, solution concentration, solution freeze temperature.
  - Linux RPU has two for FP2000
    - “Original”
    - “Storm Vision”
  - Each algorithm has a of set points that determine what voltages trigger what status values.

How to view the Algorithm set points

QTT LX-RPU Maintenance Menu

QTT LX-RPU Elite Model Version 1.17

Site	[configure] [remove log archive] [download log archive]
Configuration	[backup] [restore] [download]
Time	[configure] [display]
Network	[configure] [ppp accounts] [route table] [display] [ppplog]
Snmp Daemon	[configure]
I/O Boards	[count] [summary] [ad status] [ad1 log] [ad2 log] [serial]
AC Power Monitor	[configure] [display]
Atmospherics	[summary] [display] [wivis/pwd log] [visibility relay log]
Surface	[count] [summary] [algorithm parameters] [outpost log] [display]
SubSurface	[count] [summary] [outpost log] [display]

Algorithm details

FP2000 Storm Vision Algorithm		
1	Condensation Accumulation Scaling (0.0..5.0)	0.2
2	Frost Condition Scaling (0.0..1.0)	0.1
3	ESS Frost Threshold (0.01..1.0)	0.15
4	Surface Wet Accumulation Millimeters (0.01..20.0)	1.0
5	YesNo Surface Accumulation (0.01..1.0)	0.2
6	FP2000 Wet Scaling (0.0..1.0)	0.8
7	Dry to Damp Threshold (0.01..0.99)	0.3
8	Damp to Dry Threshold (0.01..0.99)	0.2
9	Damp to Wet Threshold (0.01..0.99)	0.6
10	Wet to Damp Threshold (0.01..0.99)	0.5
11	Well Wet Threshold (0.01..1.0)	0.85
12	Top Conductivity Threshold (0.001..0.1)	0.006
13	Well Wet Accumulation Millimeters (0.01..20.0)	6.0
14	YesNo Well Wet Accumulation (0.01..1.0)	0.25
15	Well Surface Wet Scaling (0.00..1.0)	0.2
16	Well Wet YesNo Scaling (0.00..1.0)	0.6
17	Well Wet Top Ratio Scaling (0.00..1.0)	0.85
18	Well Confidence Threshold (0.04..0.96)	0.56
19	Ice% Max Hazard (51.0..100.0)	90.0
20	Ice% Hazard At Freezepoint (0.0..1.0)	0.1
21	Ice% Hazard At 50% (0.0..1.0)	0.25
22	Ice Warning Threshold (0.04..0.96)	0.8
23	Critical Depth Millimeters (1.0..16.0)	8.0
24	Salt Absorption Rate (0.0..5.0)	0.6
25	Salt Total Absorption (0.0..5.0)	0.45

Original FP2000 Algorithm	
FP2000 Threshold C1 High (0.0..10.0)	6.86
FP2000 Threshold C1 Low (0.0..10.0)	6.60
FP2000 Threshold CH High (0.0..10.0)	4.00
FP2000 Threshold CH Low (0.0..10.0)	3.00
FP2000 Threshold CF High (0.0..10.0)	4.50
FP2000 Threshold CF Low (0.0..10.0)	9.50
FP2000 Wet to Freeze (-1.00..1.00) in Celsius	0.0
FP2000 Chemical Ice Percent to Warning Threshold (1..99) in %	85.0
FP2000 Precipitation Valid Timeframe (0..59) in minutes	30.0
FP2000 Alternate Atmospheric Valid Timeframe (0..255) in minutes	15.0
FP2000 Factory Setting (0..1)	0
FP2000 Chemical Factor Algorithm (0..1)	0

Modifications to set points

- Concentrate on “Original” for reasons to be shown later
- Threshold CH High set point:
  - Nominal = 4.0
    - Appears to be the scaled voltage at which the sensor switches from Dry to Wet.
    - Probably not very useful since as we have seen the sensor changes from min to max voltages with very little moisture change
    - Might be useful to compensate for a particular microclimate

Modifications to set points (cont)

- Example
  - Rain overnight left one sensor "wet"

Capacitance Readings	Minimum	Maximum	Current	Scaled
Low (CL)	2.3357 V	3.4201 V	3.3577 V	7.51
High (CH)	2.3269 V	3.5168 V	3.1199 V	6.25

← 07:15 AM

  - after 30 minutes, sensor about to go "dry"

Capacitance Readings	Minimum	Maximum	Current	Scaled
Low (CL)	2.3357 V	3.4201 V	3.2647 V	7.28
High (CH)	2.3269 V	3.5168 V	2.7079 V	4.05

← 07:45 AM

  - Changing transition to 6.0 would have moved transition 30 minutes earlier – probably not a big advantage

Modifications to set points (cont)

- Chemical Ice Percent to Warning Threshold
  - Determines when display changes from “Chemical Wet” to “Ice Warning”
  - Nominal = 85%   (slush is 85% frozen)
- Chemical Factor Algorithm
  - Only two choices, 0 or 1
  - Appears to modify the calculation of the solution freeze point based on percent chemical
  - Experimentation showed 0 gave more realistic results
- Wet-to-Freeze in Celsius
  - Can compensate for slight temperature variations in sensors if necessary

Some factors seen in displays

- CF = “Chemical Factor”
  - “A value between 5 and 95 that reflects relative amount of chemical in the solution”
  - It is really an estimate of chemical when the system measures a Chemical Percent close to zero
  - Displayed any time sensor is not “Dry”
- Chemical Percent
  - Concentration of chemical in the solution
  - Used to calculate the solution freeze temp
  - Only displayed when there is enough moisture in the well to get a valid reading

Typical CF change during precip

Date/Time (PDT)	Sf Stat	Temp			Chem		Water Layer		Surface		Precipitati	
		Sf	Sub	Frz	Factor	Pct	Depth	IcePct	Cond	Salin	Type	Intens
03/14/2008 00:26	Chemically Wet	29.1F	-	31F	95	5%	-	72%	13 mhos	1622	None	None
03/14/2008 00:20	Chemically Wet	29.1F	-	31F	95	5%	-	73%	13 mhos	1598	None	None
03/14/2008 00:16	Chemically Wet	29.1F	-	31F	95	5%	-	73%	13 mhos	1598	None	None
03/14/2008 00:06	Chemically Wet	29.3F	-	31F	95	3%	-	85%	7 mhos	852	Snow	Slight
03/14/2008 00:05	Chemically Wet	29.3F	-	31F	95	3%	-	85%	7 mhos	852	None	None
03/13/2008 23:56	Chemically Wet	29.5F	-	30F	95	6%	-	67%	15 mhos	1770	None	None
03/13/2008 23:50	Chemically Wet	29.5F	-	30F	95	6%	-	67%	15 mhos	1770	None	None
03/13/2008 23:46	Chemically Wet	29.5F	-	30F	95	6%	-	67%	15 mhos	1770	None	None
03/13/2008 23:46	Chemically Wet	29.5F	-	30F	95	6%	-	67%	15 mhos	1770	None	None
03/13/2008 23:36	Chemically Wet	29.5F	-	31F	95	2%	-	61%	6 mhos	643	None	None
03/13/2008 23:35	Chemically Wet	29.5F	-	31F	95	2%	-	61%	6 mhos	643	None	None
03/13/2008 23:26	Chemically Wet	31.3F	-	32F	95	1%	-	82%	3 mhos	294	None	None
03/13/2008 23:23	Chemically Wet	31.3F	-	32F	95	1%	-	82%	3 mhos	294	None	None
03/13/2008 23:20	Wet	31.3F	-	32F	95	1%	0.00 in	0%	3 mhos	277	None	None
03/13/2008 23:13	Wet	33.3F	-	32F	5	0%	0.00 in	0%	0 mhos	14	None	None
03/13/2008 23:09	Wet	33.3F	-	32F	5	0%	0.00 in	0%	0 mhos	14	Rain	Moderate
03/13/2008 23:05	Wet	33.3F	-	32F	15	0%	0.00 in	0%	0 mhos	14	Snow	Slight
03/13/2008 22:59	Wet	33.3F	-	32F	15	0%	0.00 in	0%	0 mhos	14	Snow	Slight
03/13/2008 22:50	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	13	Snow	Slight
03/13/2008 22:49	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	13	Snow	Slight
03/13/2008 22:39	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	13	None	None
03/13/2008 22:35	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	13	Snow	Slight
03/13/2008 22:29	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	13	Snow	Slight
03/13/2008 22:20	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	12	Rain	Moderate
03/13/2008 22:19	Wet	33.3F	-	32F	35	0%	0.00 in	0%	0 mhos	12	None	None

Typical effect of de-icer

Date/Time (PDT)	Sf Stat	Temp			Chem		Water Layer		Surface		Precipitation			
		Sf	Sub	Frz	Factor	Pct	Depth	IcePct	Cond	Salin	Type	Intens	Accum	Rate
03/14/2008 05:50	Chemically Wet	29.7F	-	31F	95	4%	-	78%	9 mhos	1121	Snow	Slight	-	0.0 iph
03/14/2008 05:48	Chemically Wet	29.7F	-	31F	95	4%	-	78%	9 mhos	1121	Snow	Slight	-	0.0 iph
03/14/2008 05:38	Chemically Wet	29.7F	-	31F	95	4%	-	78%	9 mhos	1121	Snow	Slight	-	0.0 iph
03/14/2008 05:35	Chemically Wet	29.7F	-	31F	95	3%	-	85%	6 mhos	762	Snow	Slight	-	0.0 iph
03/14/2008 05:28	Ice Warning	29.7F	-	31F	95	3%	-	86%	6 mhos	782	None	None	-	0.0 iph
03/14/2008 05:20	Chemically Wet	29.3F	-	31F	95	3%	-	84%	7 mhos	868	None	None	-	0.0 iph
03/14/2008 05:18	Chemically Wet	29.3F	-	31F	95	3%	-	84%	7 mhos	868	Snow	Slight	-	0.0 iph
03/14/2008 05:08	Chemically Wet	29.3F	-	30F	95	6%	-	69%	14 mhos	1726	None	None	-	0.0 iph
03/14/2008 05:05	Chemically Wet	29.3F	-	30F	95	6%	-	70%	14 mhos	1748	None	None	-	0.0 iph
03/14/2008 04:58	Chemically Wet	29.1F	-	30F	95	6%	-	68%	15 mhos	1849	None	None	-	0.0 iph
03/14/2008 04:50	Chemically Wet	29.1F	-	30F	95	6%	-	68%	15 mhos	1849	None	None	-	0.0 iph
03/14/2008 04:48	Chemically Wet	29.1F	-	30F	95	6%	-	68%	15 mhos	1849	None	None	-	0.0 iph
03/14/2008 04:37	Chemically Wet	29.1F	-	30F	95	6%	-	71%	14 mhos	1765	None	None	-	0.0 iph
03/14/2008 04:35	Chemically Wet	28.9F	-	30F	95	6%	-	70%	15 mhos	1805	Snow	Slight	-	0.0 iph
03/14/2008 04:27	Chemically Wet	28.9F	-	30F	95	6%	-	72%	15 mhos	1844	Snow	Slight	-	0.0 iph
03/14/2008 04:20	Chemically Wet	28.8F	-	30F	95	6%	-	73%	14 mhos	1795	Snow	Slight	-	0.0 iph
03/14/2008 04:17	Chemically Wet	28.8F	-	30F	95	6%	-	73%	14 mhos	1795	Snow	Slight	-	0.0 iph
03/14/2008 04:07	Chemically Wet	28.2F	-	30F	95	7%	-	71%	16 mhos	2095	Snow	Slight	-	0.0 iph
03/14/2008 04:05	Chemically Wet	28.2F	-	30F	95	7%	-	71%	16 mhos	2095	Snow	Slight	-	0.0 iph
03/14/2008 03:57	Chemically Wet	28.2F	-	30F	95	7%	-	74%	16 mhos	2229	Snow	Slight	-	0.0 iph
03/14/2008 03:50	Chemically Wet	27.3F	-	30F	95	8%	-	70%	18 mhos	2493	Snow	Slight	-	0.0 iph
03/14/2008 03:47	Chemically Wet	27.3F	-	29F	95	9%	-	73%	18 mhos	2678	Snow	Slight	-	0.0 iph
03/14/2008 03:37	Chemically Wet	26.4F	-	30F	95	7%	-	77%	15 mhos	2209	None	None	-	0.0 iph
03/14/2008 03:35	Chemically Wet	26.4F	-	30F	95	7%	-	77%	15 mhos	2209	None	None	-	0.0 iph
03/14/2008 03:27	Chemically Wet	26.6F	-	30F	95	7%	-	78%	14 mhos	2093	None	None	-	0.0 iph
03/14/2008 03:20	Chemically Wet	26.6F	-	30F	95	7%	-	78%	14 mhos	2067	None	None	-	0.0 iph
03/14/2008 03:17	Chemically Wet	26.8F	-	30F	95	7%	-	79%	13 mhos	1964	None	None	-	0.0 iph
03/14/2008 03:07	Chemically Wet	26.8F	-	30F	95	6%	-	79%	13 mhos	1940	None	None	-	0.0 iph
03/14/2008 03:05	Chemically Wet	26.8F	-	30F	95	6%	-	79%	13 mhos	1940	None	None	-	0.0 iph
03/14/2008 02:57	Ice Warning	27.0F	-	31F	95	4%	-	86%	8 mhos	1251	None	None	-	0.0 iph

Which algorithm is better?

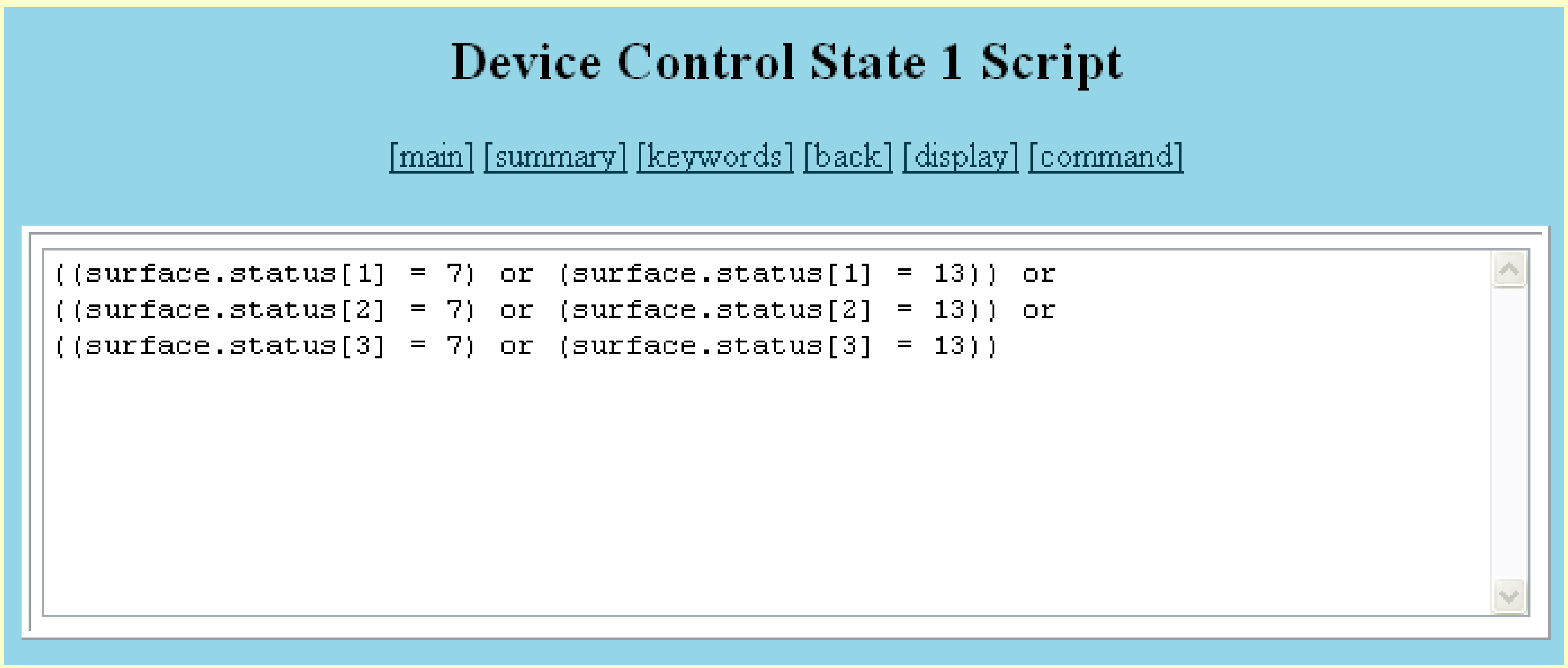
- Storm Vision
  - Many more configurable values
  - "Fuzzy Logic" based
- Original
  - Less flexible (fewer configuration values)
  - Easier to configure by experimentation
- Choice driven by:
  - SSI won't help with experimentation
    - Detailed questions about operation result in answers like "The system is working as expected"
  - Outpost sensors can only use "Original"
    - Outpost does not return raw values to RPU, only scaled values
    - Storm Vision uses raw values to calculate additional terms
  - Mixing algorithms on the same system result in inconsistent results between sensors for the same observed conditions.
- We chose "Original" due to Outpost limitations

System modifications based on research

- Modify the sign control scripts to use the sensor status only (instead of temp + status)
  - Turn signs on only in “Ice Warning” and “Frost” conditions (previously turned on when “not Dry”)
  - Signs will stay off when de-icer is sufficient to keep solution from freezing
  - Signs will stay off when small amounts of moisture (insufficient to allow for the formation of ice) are present
    - “Trace Moisture” and temp < Freeze Point = “Ice Watch”
- Keep the signs on for 20 minutes after “on” condition has become false
  - Stops sign blinking at temps near the freezing point

System modifications based on research

- Final control script is simpler
  - Previously had a separate script for “Frost”, now Frost is determined by the system itself
  - Many of the status states defined in the scripting language are not used on Linux system, so less chance of an errant state keeping the signs on



System modifications based on research

Surface Status Codes	Codes
surface.other	1
surface.error	2
surface.dry	3
surface.trace	4
surface.wet	5
surface.chemwet	6
surface.icewarning	7
surface.icewatch	8
surface.snowwarning	9
surface.snowwatch	10
surface.absorption	11
surface.dew	12
surface.frost	13
surface.absorptiondew	14

Only use states that reflect ice conditions on a Linux RPU:

← Use this state (surface.icewarning, 7)

← Use this state (surface.frost, 13)

System modifications based on research

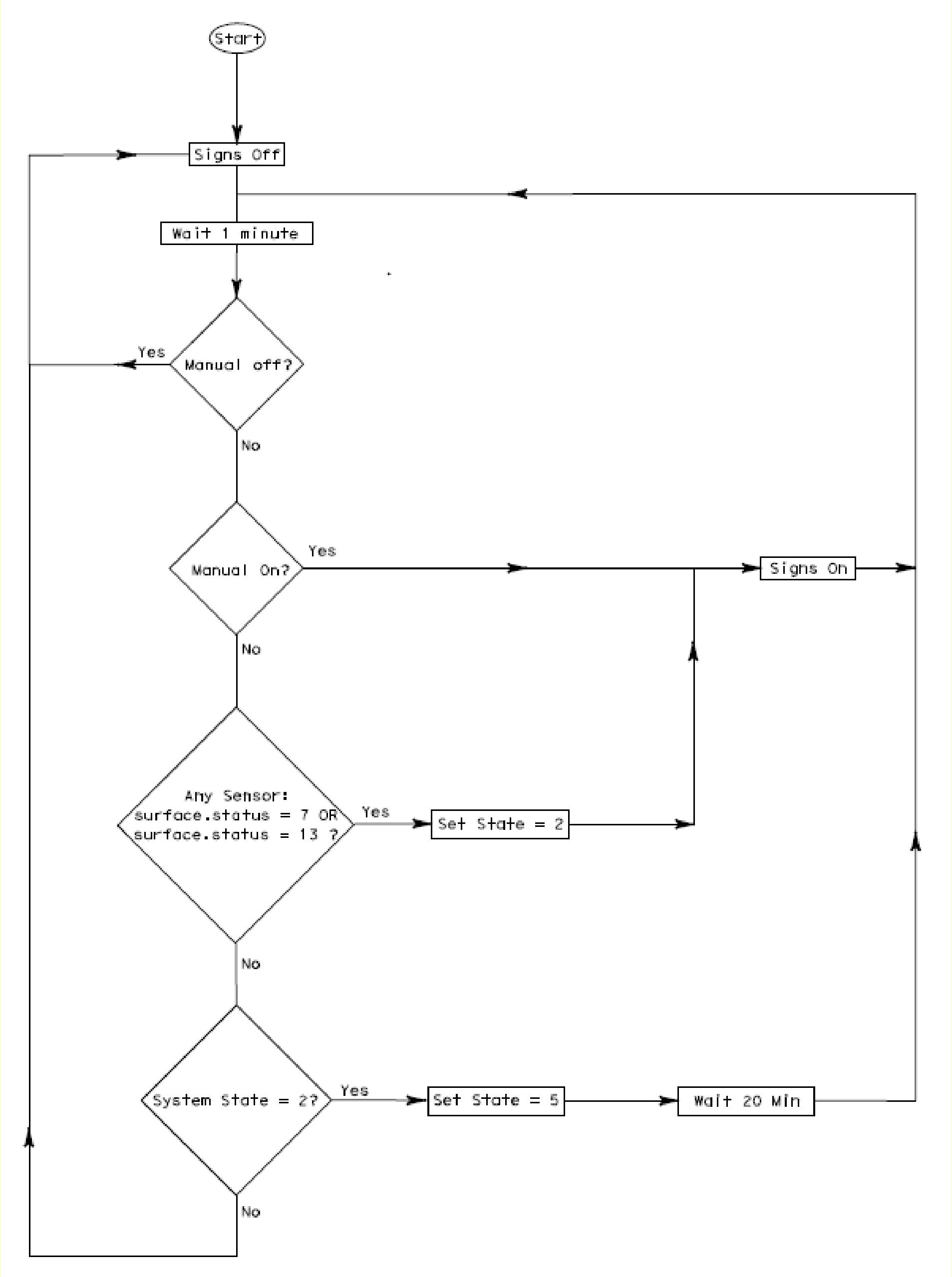
Definition of surface states (SSI glossary)

Status	Description
Snow/Ice Warning	Continuous film of ice and water mixture at or below freezing (32°F / 0°C) with insufficient chemical to keep the mixture from freezing. This status can only be reported at SSI ESP and SP sites when precipitation occurs.
Ice Warning	Continuous film of ice and water mixture at or below freezing (32°F / 0°C) with insufficient chemical to keep the mixture from freezing. This status can only be reported at NTCIP sites.
Snow Warning	This status can be reported at NTCIP sites, but will not be reported by SSI NTCIP sites.
Wet Below Freezing	Moisture on pavement sensor with a surface temperature below freezing (32°F / 0°C). This status will only be reported at SSI SCAN Detector sites.
Frost	Moisture on pavement at or below freezing (32°F / 0°C) with a pavement temperature at or below the dew point temperature. This status can only be reported by SSI ESP, SP, and NTCIP sites when precipitation is not occurring.
Ice Watch	Thin or spotty film of moisture at or below freezing (32°F / 0°C). This status can only be reported at NTCIP sites when precipitation is not occurring.
Snow Watch	This status can be reported at NTCIP sites, but is not detected at SSI NTCIP sites.
Snow/IceWatch	Thin or spotty film of moisture at or below freezing (32°F / 0°C). This status can only be reported at SSI ESP and SP sites when precipitation is not occurring.
Chemical Wet	Continuous film of water and ice mixture at or below freezing (32°F or 0°C) with enough chemical to keep the mixture from freezing. This status can only be reported by SSI ESP, SP, and NTCIP sites when precipitation occurs.
Wet	Continuous film of moisture on the pavement sensor with a surface temperature above freezing (32°F or 0°C). This status can be reported by SSI ESP, SP, SCAN Detector, and NTCIP sites when precipitation has occurred.
Damp	Thin or spotty film of moisture above freezing (32°F or 0°C). This status can only be reported by SSI ESP, and SP sites when precipitation is not occurring.
Trace Moisture	Thin or spotty film of moisture above freezing (32°F or 0°C). Surface moisture occurred without precipitation being detected. This status will only be reported at NTCIP sites when precipitation is not occurring.
Absorption at Dew Point, Absorption, & Dew	These statuses can be reported at NTCIP sites, but are not currently detected at SSI NTCIP sites.
Dry	Absence of moisture on the surface sensor. This status can be reported by SSI ESP, SP, SCAN Dectector, and NTCIP sites.
Other	Other is the standard NTCIP ESS surface condition code to handle conditions not explicitly included in this table. This status will only be reported NTCIP by sensors installed at NTCIP ESS sites.
No Report	The surface sensor is not operating properly and requires maintenance. This status will only be reported by SSI ESP and SP sites.
Error	The surface sensor is not operating properly and requires maintenance. This status will only be reported by NTCIP sites.

note: Linux RPU = SSI NTCIP site

System modifications based on research

Final sign control flow chart



Note 1: Loop is executed continuously. "Wait" conditions stop execution for the noted time.

Note 2: Loop executes even when "manual off" or "manual on" are active

Other problem observed

- Days that were known to be clear were showing occasional “snow” on the WIVIS™ precipitation sensor
  - The system algorithm would drive the sensor status to “trace moisture” based on this info even if surface sensor did not detect moisture
  - Ice crystals falling from the trees surrounding the RWIS tower were being seen by the precipitation sensor
    - Since WIVIS™ is a serial device, we could relocate the instrument to the camera site on the roadway.

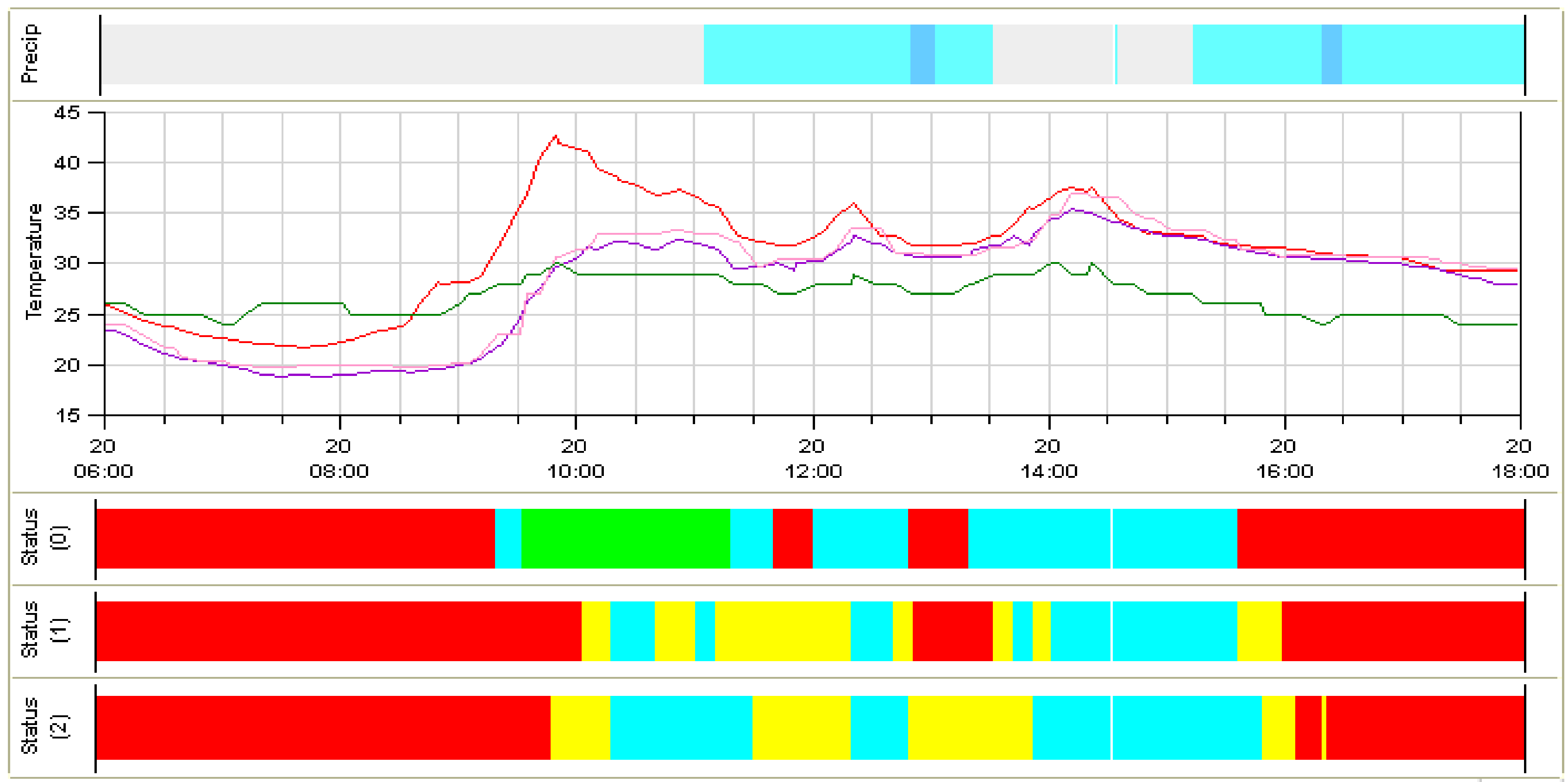
Be careful where you put a RWIS

Results

- Systems appear to be giving more realistic indications
- Signs are staying off during cold (<32F) clear days.
- Signs turn on when precipitation is present in small amounts and temp is low enough
- Signs are staying off when enough deicer is present
- Maintenance procedure is to place deicer only in the area of sensors #2 and #3
  - Sensor #1 is generally warmer and drier than #2 and #3, so this may not be an issue
  - Careful inspection of history records can show uneven application of deicer
  - Can show loss of deicer effectiveness

Results (cont)

- Uneven deicer
  - Yellow (chemically wet) starts earlier, stays active, and ends later on one sensor than the other
  - Sensor 0 (summit) is not treated at all



Results (cont)

Loss of deicer effectiveness

Date/Time (PDT)	Sf Stat	Temp			Chem		Water Layer		Surface		Precipitation			
		Sf	Sub	Frz	Factor	Pct	Depth	IcePct	Cond	Salin	Type	Intens	Accum	Rate
01/30/2008 17:12	Ice Warning	30.2F	-	32F	90	0%	-	98%	1 mhos	76	Snow	Slight	-	0.0 iph
01/30/2008 17:05	Ice Warning	30.2F	-	32F	90	0%	-	97%	1 mhos	73	Snow	Slight	-	0.0 iph
01/30/2008 17:02	Ice Warning	30.7F	-	32F	90	0%	-	97%	1 mhos	94	Snow	Slight	-	0.0 iph
01/30/2008 16:52	Ice Warning	31.1F	-	32F	95	0%	-	94%	1 mhos	123	Snow	Slight	-	0.0 iph
01/30/2008 16:50	Ice Warning	31.1F	-	32F	95	0%	-	94%	1 mhos	123	Snow	Slight	-	0.0 iph
01/30/2008 16:42	Ice Warning	31.1F	-	32F	95	0%	-	94%	1 mhos	123	Snow	Slight	-	0.0 iph
01/30/2008 16:35	Ice Warning	31.5F	-	32F	95	0%	-	89%	1 mhos	143	Snow	Slight	-	0.0 iph
01/30/2008 16:32	Ice Warning	31.5F	-	32F	95	0%	-	89%	1 mhos	143	Snow	Slight	-	0.0 iph
01/30/2008 16:22	Chemically Wet	31.8F	-	32F	95	1%	-	68%	2 mhos	176	Snow	Slight	-	0.0 iph
01/30/2008 16:20	Chemically Wet	31.8F	-	32F	95	1%	-	68%	2 mhos	176	Snow	Slight	-	0.0 iph
01/30/2008 16:12	Wet	31.8F	-	32F	95	1%	0.00 in	0%	2 mhos	174	Snow	Slight	-	0.0 iph
01/30/2008 16:05	Wet	32.2F	-	32F	95	1%	0.00 in	0%	2 mhos	194	Snow	Slight	-	0.0 iph
01/30/2008 16:02	Wet	32.2F	-	32F	95	1%	0.00 in	0%	2 mhos	194	Snow	Slight	-	0.0 iph
01/30/2008 15:52	Wet	32.5F	-	32F	95	1%	0.00 in	0%	2 mhos	192	Snow	Slight	-	0.0 iph

Results (cont)

- Maintenance personnel report signs appear to be giving a more accurate indication of conditions
- Surface sensors have proven themselves capable of providing repeatable data
  - “Accuracy” somewhat dependent on conditions (micro-climate)
  - Probably need to correlate system data with actual (observed) conditions at each site
- If anything, sensors are overly conservative when determining ice conditions

Surface Sensor Troubleshooting

Surface Sensor Troubleshooting

- Sensor status is ‘Error’ (Linux) or ‘No Report’ (Old RPU)
  - Linux: check that Max and Min CL/CH Wet/Dry values saved on Surface – Summary – Configure page are within the window of Dry/Wet cal values.
    - Use “Accept Dry/Wet Values” buttons to set new cal values
    - Careful: these values are only saved since the last sensor daemon (sensord) restart
    - Must restart sensord to get RPU to use the new values
  - Old DOS-based RPU and pucks on Outpost: use command interface to (D)isplay raw values when the error is being displayed.
    - Use (S)etup command to show the cal values. If the displayed raw value is outside the cal window, change the cal value to the displayed value. Pay attention to whether they are the Wet or Dry values.

Surface Sensor Troubleshooting (cont)

- Wet/Dry Max/Min values saved:
  – Surface – Summary - Configure

FP2000 CL Dry (0.0..8.0) vdc	2.354
FP2000 CL Wet (0.0..8.0) vdc	3.435
FP2000 CH Dry (0.0..8.0) vdc	2.359
FP2000 CH Wet (0.0..8.0) vdc	3.491
FP2000 RWL (0.0..8.0) vdc	.400
FP2000 RTL (0.0..8.0) vdc	.503
Cable Resistance (0.0..100.0) ohms	18.5

FP2000 Wet/Dry Calibration		
FP2000 CL Minimum (Dry Reading)	2.351918	Accept Dry Values
FP2000 CH Minimum (Dry Reading)	2.357797	
FP2000 CL Maximum (Wet Reading)	3.505997	Accept Wet Values
FP2000 CH Maximum (Wet Reading)	3.558730	

Reset Form | Save

Surface Sensor Troubleshooting (cont)

DOS RPU not as easy:

```
Display Surface Sensor Number(1..3): 3
Time = 1206454475, Tue Mar 25 14:14:35 2008□
SurfTemp =    5.87 C,   42.56 F     586 R
  FP2000
  Top1      Top2      Botm      Refr
   5.87      5.87      5.87      5.74  Deg C.
  42.56     42.56     42.56     42.33  Deg F.
    586       586       586       573  R

    CL      RWL      RWM      RWH      CH       RTL      RTM      RTH
  3.478*  6.891*  0.231*  0.012*  4.365*  8.048*  8.051*  0.667*
   8.69*#######*#######*    3.36*  13.27*#######*#######*#######
 7  6.9* 0  5.9* 1  5.0* 2  4.0* 3  3.0* 4  2.0* 5  1.0* 6  0.0*

ErrC=00 Current   563 Total   0 Bad
FP=  164.26 C,  327.67 F   32767 R
Ice=  255 %  255 R    Chem= 255 %  255 R    Depth=   2.550 in, 65535 R
Ctiv=   2.64 mmho    ChemFactor= 255  255R
  Cond =  SensorDown95    Stat =  Sensor Down
```

CH scaled >> 8.0 V

Surface Sensor Troubleshooting (cont)

```
List Change Add Delete Save Help Return: c3

Change
Modify Sensor (1..9):
1 Sensor Type:

Align FP2000 at position 3 from
Data Wet/dry?: D

   2.324 CL_Dry:
   3.359 CL_Wet:  3.478

   2.326 CH_Dry:

   3.412 CH_Wet:  4.365

Voltages Set.
   0.366 Prod Data Sheet RWL SaltWater(typ 0.337):

   0.463 Prod Data Sheet RTL SaltWater(typ 0.455):

KWell =  1.085
KTop  =  1.016
Sensor Aligned
  36.500 Cable Ohms=

List Change Add Delete Save Help Return: r
```

Use values from Display function

Surface Sensor Troubleshooting

- Some sensor conditions are "terminal"

```
  CL      RWL     RWM     RWH      CH      RTL     RTM     RTH
 0.559*  6.631*  6.631*  6.631* -0.410*  6.631*  6.631*  1.680*
 -1.66*#######*#######*   6.34* -19.06*#######*#######*#######
7   6.8* 0   6.1* 1   5.1* 2   4.1* 3   3.2* 4   2.2* 5   1.3* 6   0.3*

ErrC=00 Current   1157 Total   0 Bad
FP=  164.26 C,  327.67 F   32767 R
Ice=  255 %  255 R    Chem= 255 %  255 R    Depth=   2.550 in, 65535 R
Ctiv=   0.00 mmho    ChemFactor= 255  255R
  Cond =  SensorDown95    Stat =  Sensor Down
```

- Raw values should never be negative:
  - If they are, "get a chisel"
- If only the scaled value is negative, try changing the cal value and hope for the best.

General Troubleshooting

- Linux RPU logs:
  - Standard Linux distribution, logs in /var/log
    - /var directory is actually in /ram/var
    - /ram is a ram drive (to save wear and tear on the flash drive)
    - files disappear when system is restarted
- logs can be ‘archived’ using selection on config page
  - This is the ‘messages’ file as used in Linux
- logs must be downloaded after archiving to view
- log files are owned by ‘root’ without read permission to anyone else
  - no console view
  - no ftp

General Troubleshooting (cont)

QTT LX-RPU Maintenance Menu

QTT LX-RPU Elite Model Version 1.17

Site	[configure] [create log archive]
Configuration	[backup] [restore] [download]

QTT LX-RPU Maintenance Menu

QTT LX-RPU Elite Model Version 1.17

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Site	[configure] [remove log archive] [download log archive]
Configuration	[backup] [restore] [download]

General Troubleshooting (cont)

- Typical log file

```
Mar 25 16:38:34 localhost reportd: New Report Time Passed
Mar 25 16:38:34 localhost reportd: Saving History
Mar 25 16:38:52 localhost thttpd[15063]: socket :: - Address family not supported by protocol
Mar 25 16:38:52 localhost thttpd[15063]: thttpd/2.25b 29dec2003 starting on port 80
Mar 25 16:38:52 localhost thttpd[15063]: started as root without requesting chroot(), warning only
Mar 25 16:39:12 localhost thttpd[15063]: 10.16.8.81 - - "GET /cgi-bin/formfactory?form-id=cfg-main
HTTP/1.1" 401 0 "" "Mozilla/5.0 (Windows; U; Windows NT 5.1; en-US; rv:1.8.1.12) Gecko/20080201
Firefox/2.0.0.12"
Mar 25 16:39:14 localhost thttpd[15063]: spawned CGI process 15070 for file 'cgi-bin/formfactory'
Mar 25 16:39:14 localhost thttpd[15063]: 10.16.8.81 - maint "GET /cgi-bin/formfactory?form-id=cfg-main
HTTP/1.1" 200 25000 "" "Mozilla/5.0 (Windows; U; Windows NT 5.1; en-US; rv:1.8.1.12) Gecko/20080201
Firefox/2.0.0.12"
Mar 25 16:39:17 localhost thttpd[15063]: 10.16.8.81 - - "GET /favicon.ico HTTP/1.1" 404 0 "" "Mozilla/5.0
(Windows; U; Windows NT 5.1; en-US; rv:1.8.1.12) Gecko/20080201 Firefox/2.0.0.12"
Mar 25 16:39:18 localhost sensord: WIVIS: C
Mar 25 16:39:18 localhost thttpd[15063]: 10.16.8.81 - - "GET /favicon.ico HTTP/1.1" 404 0 "" "Mozilla/5.0
(Windows; U; Windows NT 5.1; en-US; rv:1.8.1.12) Gecko/20080201 Firefox/2.0.0.12"
Mar 25 16:39:26 localhost thttpd[15063]: spawned CGI process 15086 for file 'cgi-bin/formfactory'
Mar 25 16:39:26 localhost thttpd[15063]: 10.16.8.81 - maint "GET
/cgi-bin/formfactory?form-id=cfg-log-backup HTTP/1.1" 200 25000
"http://10.20.199.136/cgi-bin/formfactory?form-id=cfg-main" "Mozilla/5.0 (Windows; U; Windows NT 5.1;
en-US; rv:1.8.1.12) Gecko/20080201 Firefox/2.0.0.12"
```

General Troubleshooting (cont)

- Using telnet/ssh interface on Linux
  - Standard Telnet/SSH connection
  - ‘user’ login does not have root privileges
  - Processes can be started/restarted using ./admin
    - Really useful when thttpd daemon quits:
      - change to /scan/bin
      - ‘./admin start thttpd’
    - can use ‘shutdown’ command also to reboot

General Troubleshooting (cont)

- System keeps a log of A/D activity
  - I/O Boards – ad1 log: provides time stamped sensor data
  - Time stamps are seconds since last restart
  - Only about 30 seconds or so of data
    - Difficult to see puck data (1 minute updates)

QTT LX-RPU Maintenance Menu

QTT LX-RPU Elite Model Version 1.17

Site	[configure] [remove log archive] [download log archive]
Configuration	[backup] [restore] [download]
Time	[configure] [display]
Network	[configure] [ppp accounts] [route table] [display] [ppplog]
Snmp Daemon	[configure]
I/O Boards	[count] [summary] [ad status] [ad1 log] [ad2 log] [serial]

General Troubleshooting (cont)

AD1 Log

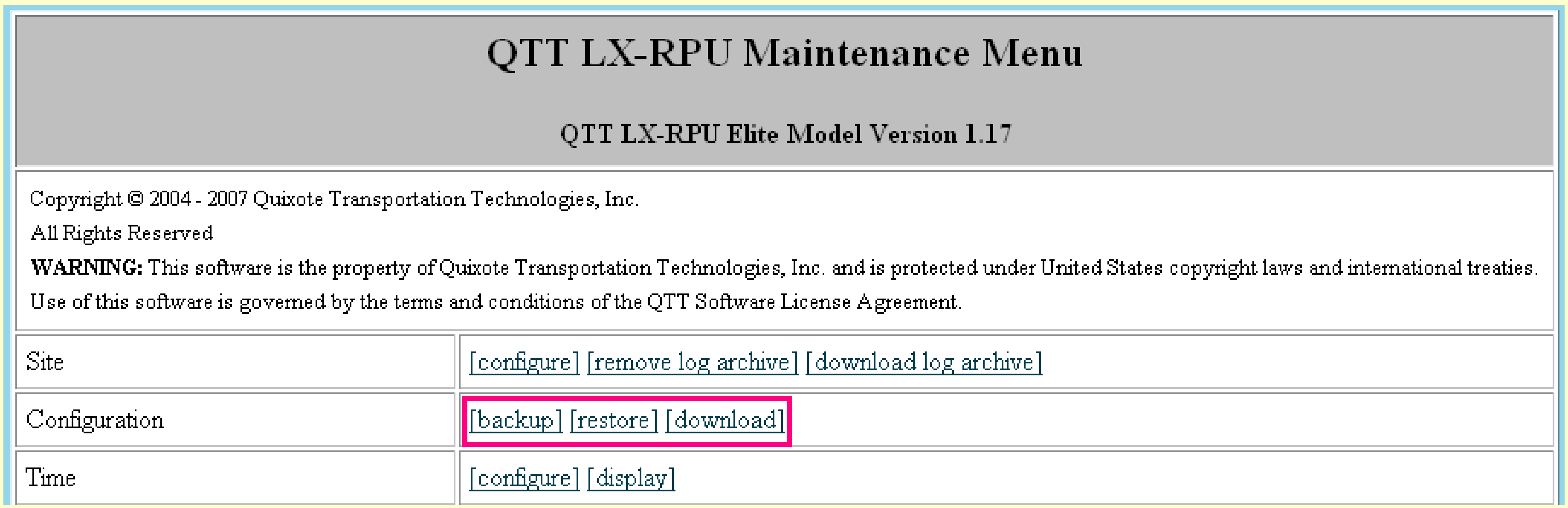
[main]

Current Time	Tue Mar 25 19:35:55 2008 UTC

TimeStamp	Name	Type	Channel	Terminal	Value
2415536.360	rh	Analog	31	[B-U/TREF [5 Vdc] Reference]	4.9998
2415536.480	sub0	Analog	08	[A-TS3 3+2- [+/-12 Vdc] Temperature/Generic]	2.9290
2415536.620	sub0	Analog	15	[A-U/TREF [5 Vdc] Reference]	4.9998
2415536.760	idle	Analog	15	[A-U/TREF [5 Vdc] Reference]	4.9998
2415536.880	air	Analog	29	[B-TS5 4+ [0-6.5 Vdc] Generic]	2.9964
2415537.020	air	Analog	31	[B-U/TREF [5 Vdc] Reference]	4.9998
2415537.140	rh	Analog	30	[B-TS5 5+ [0-6.5 Vdc] Generic]	1.8101
2415537.290	rh	Analog	31	[B-U/TREF [5 Vdc] Reference]	4.9998
2415537.410	sub0	Analog	08	[A-TS3 3+2- [+/-12 Vdc] Temperature/Generic]	2.9290
2415537.550	sub0	Analog	15	[A-U/TREF [5 Vdc] Reference]	4.9998
2415537.680	idle	Analog	15	[A-U/TREF [5 Vdc] Reference]	4.9998
2415537.810	air	Analog	29	[B-TS5 4+ [0-6.5 Vdc] Generic]	2.9964
2415537.950	air	Analog	31	[B-U/TREF [5 Vdc] Reference]	4.9998
2415538.070	wind	Counter	01	[B-TS5 7 Counter]	216

Good Practices

- Disaster recovery: I did something and now it doesn't work!
  - Backup configurations before doing anything
  - Easy with Linux to keep copies off-site
  - Can also be reloaded through telnet/ftp



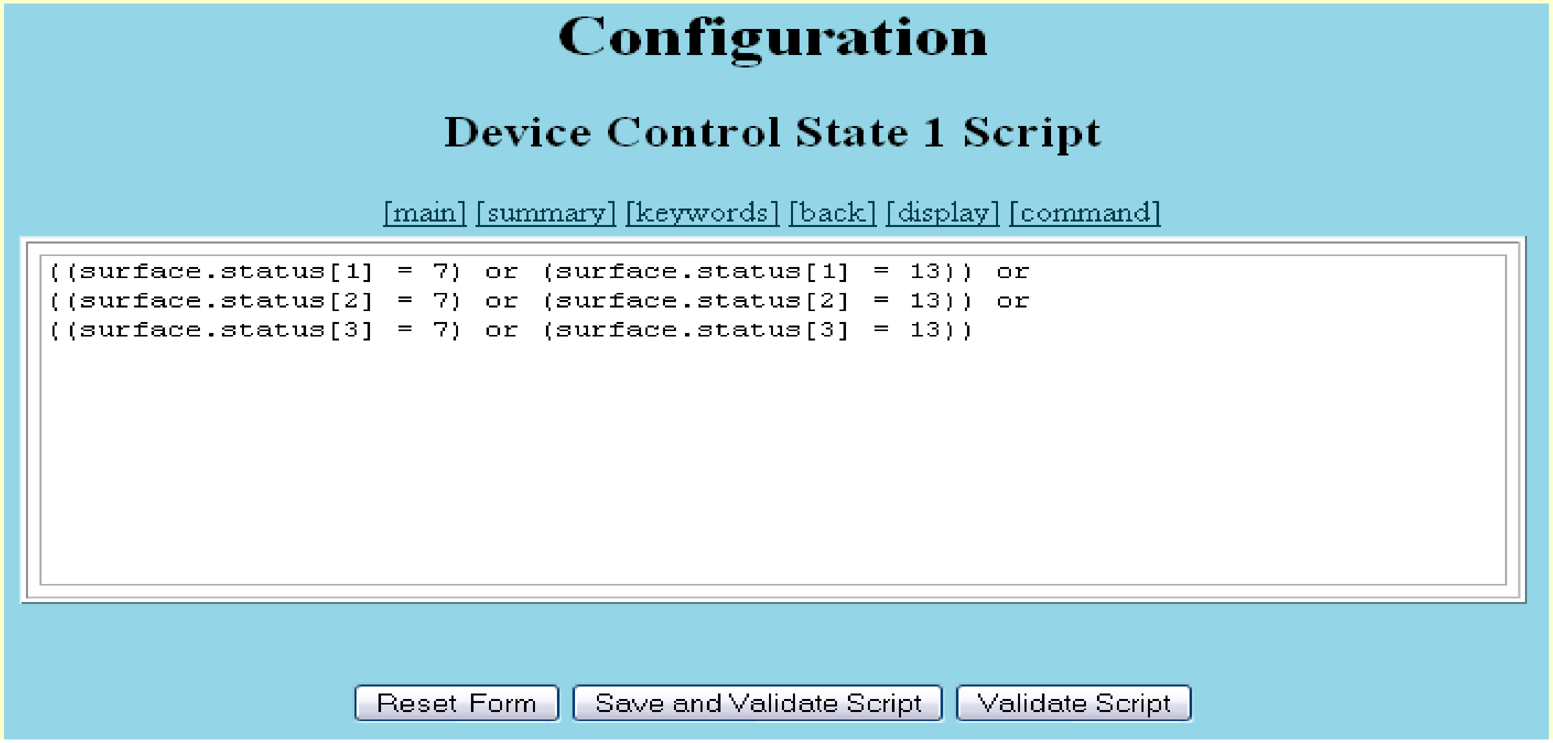
QTT LX-RPU Maintenance Menu

QTT LX-RPU Elite Model Version 1.17

Site	[configure] [remove log archive] [download log archive]
Configuration	[backup] [restore] [download]
Time	[configure] [display]

Good Practices

- When updating scripts:
  - “Save and validate” every time
  - Don’t forget to restart sensord when changes are complete
  - Save and download a new backup config file after changes are complete



Conclusions

- RWIS is capable of reasonably accurate reporting of icy conditions
- Proper calibration of surface sensors is critical to operation
  - Calibration will drift over time and amount of traffic
- All sites will have their own distinct "micro climate".
  - Some adjustments to the system may be necessary to ensure accuracy and repeatability.
- Placement of the RWIS with respect to surface features is critical.
- Placement of surface sensors can have major impact on accuracy

Future Plans

- Develop an ongoing process to check the accuracy of each RWIS
  - Use portable RWIS with data logging to cross-check atmospheric data
  - Use portable temp sensor (IR or contact) to confirm surface sensor temp accuracy
  - Use surface sensor test procedure to confirm status accuracy
  - Automate the puck data collection using microcontroller and voltmeter with data port

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Questions & Comments