An Evaluator for FDD Algorithms

Workshop: Automated FDD for RTU's – Moving from R&D to Commercialization
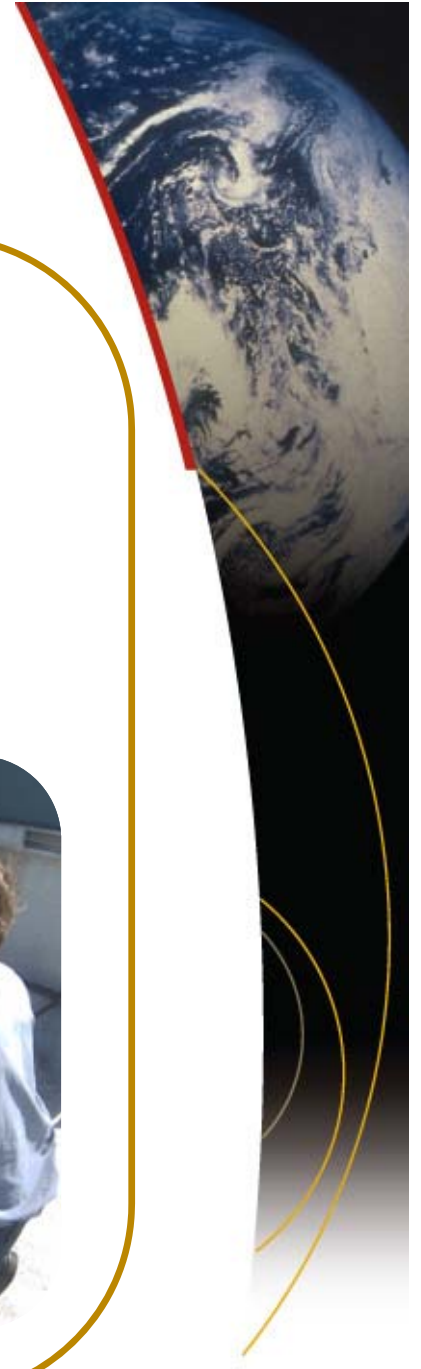
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Background

- **We don't know how well FDD works**

- FDD for unitary vapor compression equipment

  - RTU and Split systems

  - Spot check tools (not onboard)

- Need <u>evaluation methodology</u>

  - Full performance characterization

  - Test method

  - Input data (ground truth)

  - Performance metrics

Scope

Fault categories

1. Undercharge
2. Overcharge
3. Evaporator fouling
4. Condenser fouling
5. Liquid line restriction
6. Non-condensables
7. Compressor valve leakage

Systems

Air-cooled VC cycle

Split systems and packaged
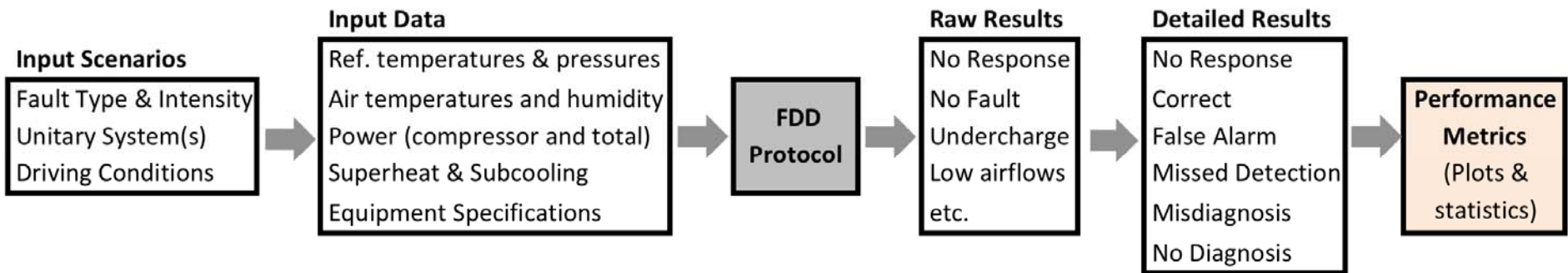
Operating at steady-state

Objectives

-Develop methodology for measuring FDD protocol performance

-Rating system
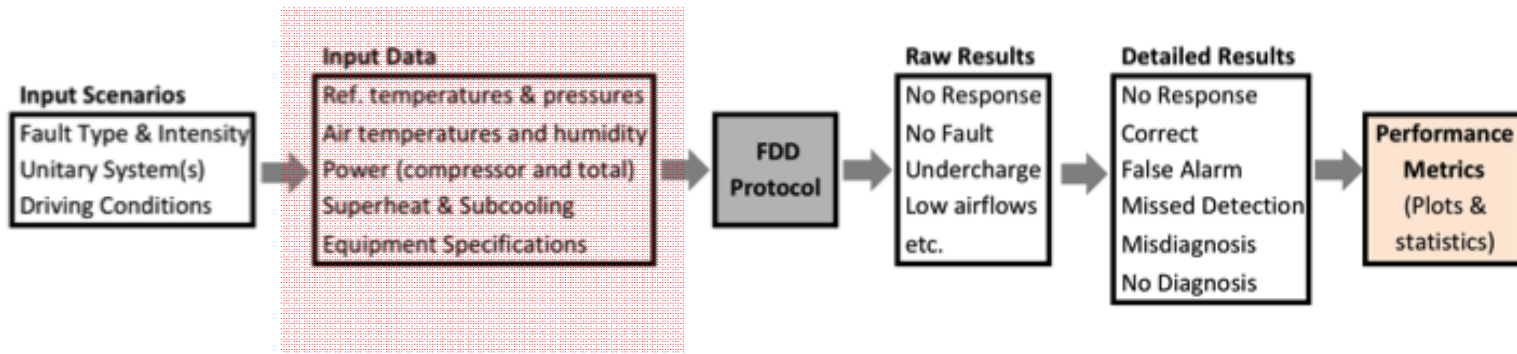
-Evaluator software

Evaluation Requirements
- Consistent results in repeated evaluations
- Reflect utility of the protocol to end user
- Not too burdensome
- Accommodate all protocols

Approach – Overview

Input Scenarios

| Fault Type & Intensity |
| Unitary System(s) |
| Driving Conditions |

Input Data

| Ref. temperatures & pressures |
| Air temperatures and humidity |
| Power (compressor and total) |
| Superheat & Subcooling |
| Equipment Specifications |

FDD Protocol

Raw Results

| No Response |
| No Fault |
| Undercharge |
| Low airflows |
| etc. |

Detailed Results

| No Response |
| Correct |
| False Alarm |
| Missed Detection |
| Misdiagnosis |
| No Diagnosis |

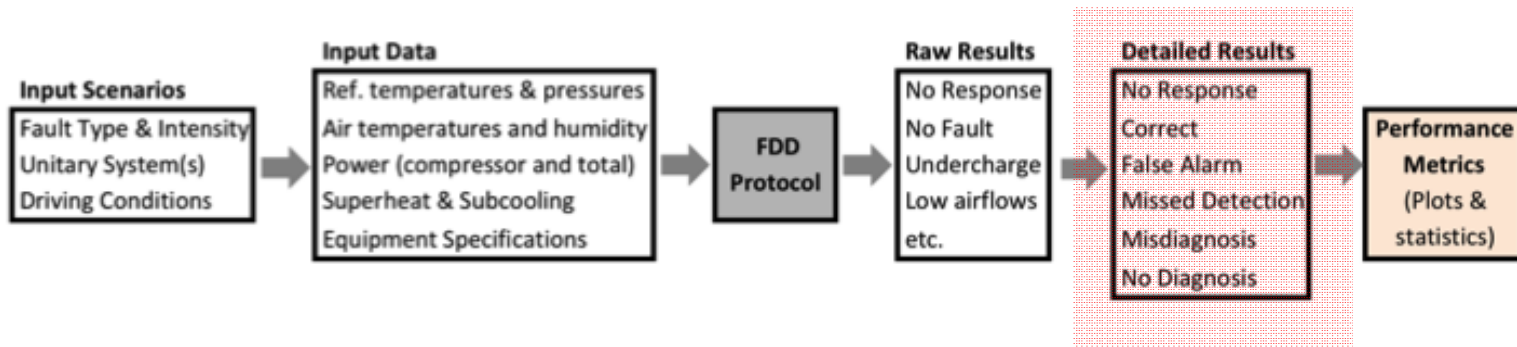**Performance Metrics**
(Plots & statistics)

Approach – Input Data

- Simulations (Cheung & Braun 2013a,b)

- Started with experimental data
  - Not sufficient for good evaluation

- 14,074 scenarios

- Even distribution of inputs
  - 8 units
  - ambient & indoor conditions
 - fault intensities

Approach – Detailed Results

- Possible outcomes
  - No Response
  - Correct
  - False Alarm (detection with no significant fault)
  - Missed Detection
  - Misdiagnosis
  - No Diagnosis (correct detection)

- Organize on the basis of Fault Impact Ratio (FIR)

$$FIR_{COP} = \frac{COP_{faulted}}{COP_{unfaulted}} \qquad FIR_{capacity} = \frac{capacity_{faulted}}{capacity_{unfaulted}}$$

Example Evaluations

- Five protocols
  - RCA-2013 from Title 24
  - Four other commercial or utility protocols
  - No Diagnosis (correct detection)

- Results
  - False Alarm Rates
  - Misdiagnosis Rates
  - Missed Detection Rates
  - No Diagnosis Rates
  - Confusion
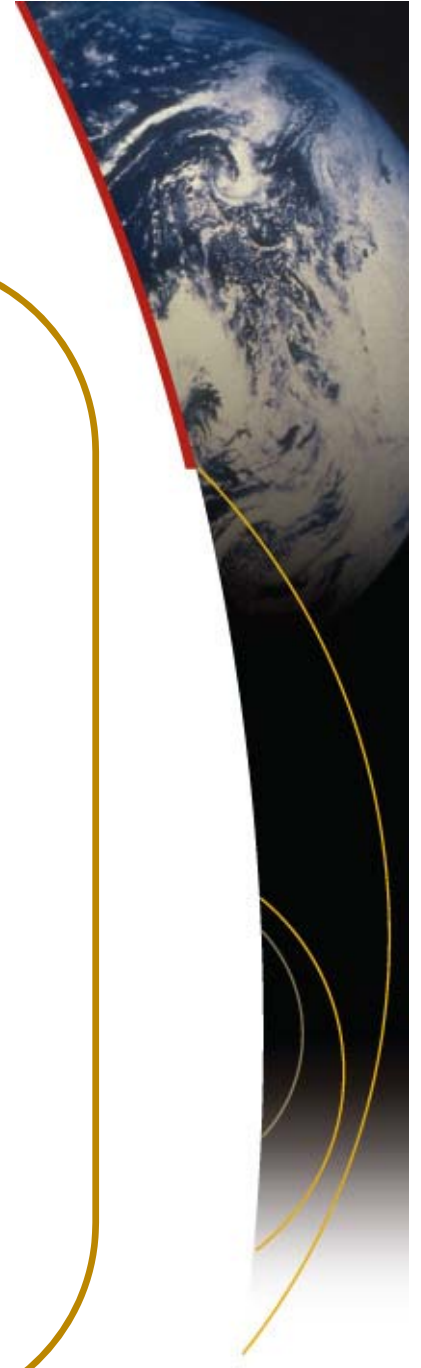
Example Evaluations

- ## False Alarms
  - FDD detects fault
  - No *significant* fault is present
  - Analyzed for several significance thresholds

The fine print:

1) $FIR_{capacity}$ <u>and</u> FIR_{COP} are above threshold
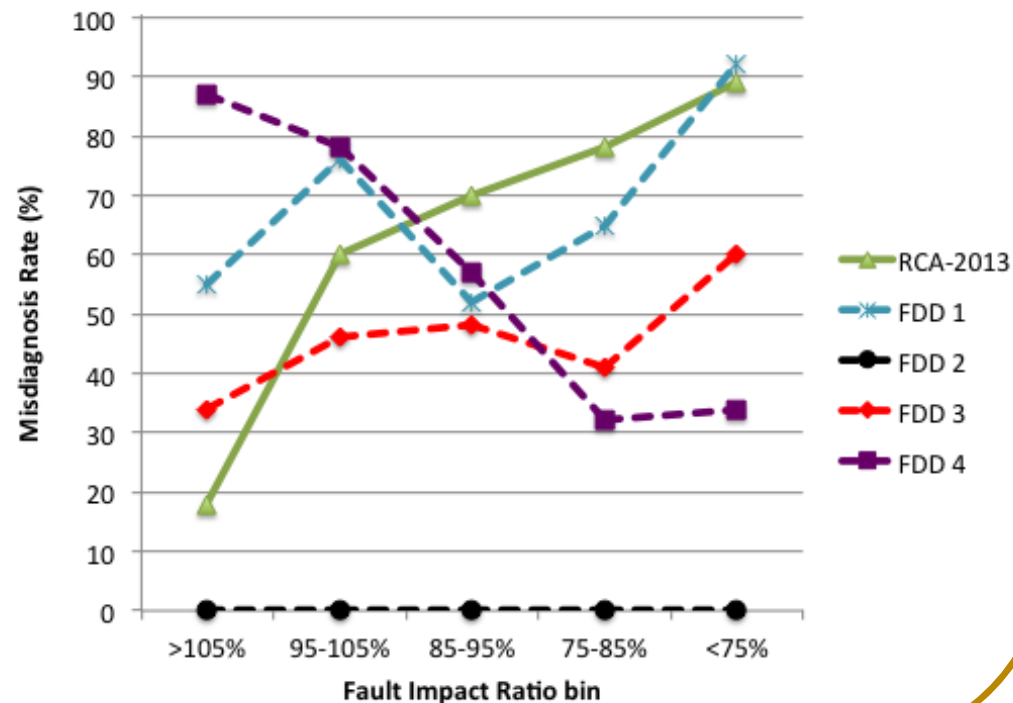2) No false alarm if:
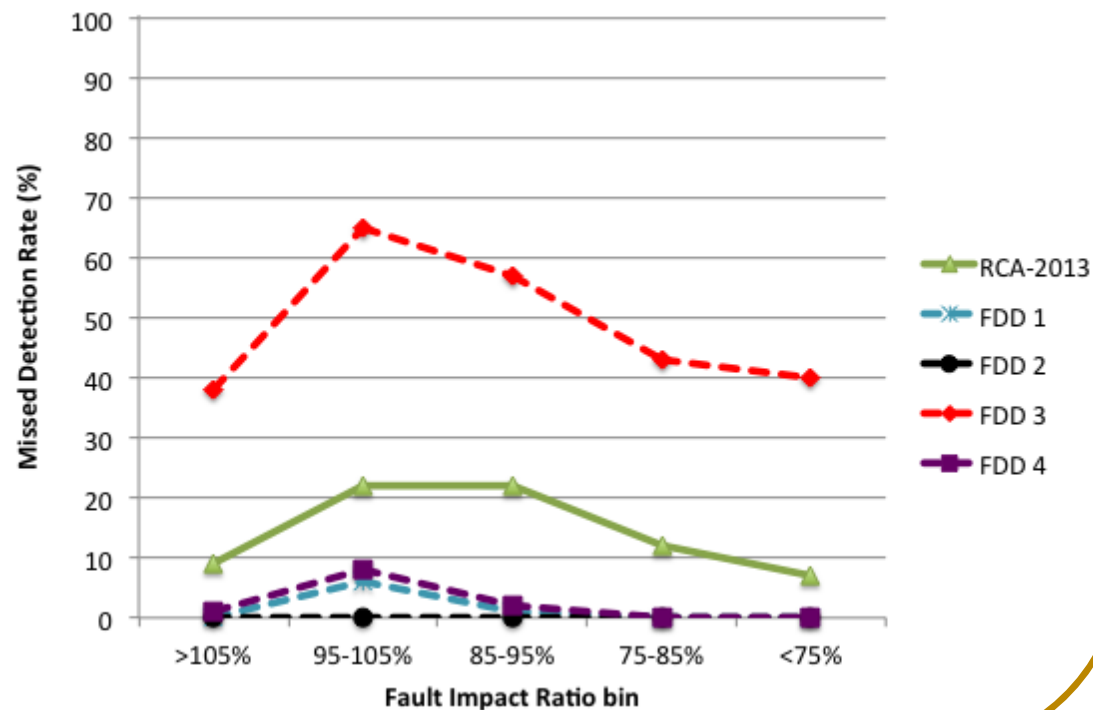 If SH < 1
  or
  SH > 36
  or
  Charge > 105%
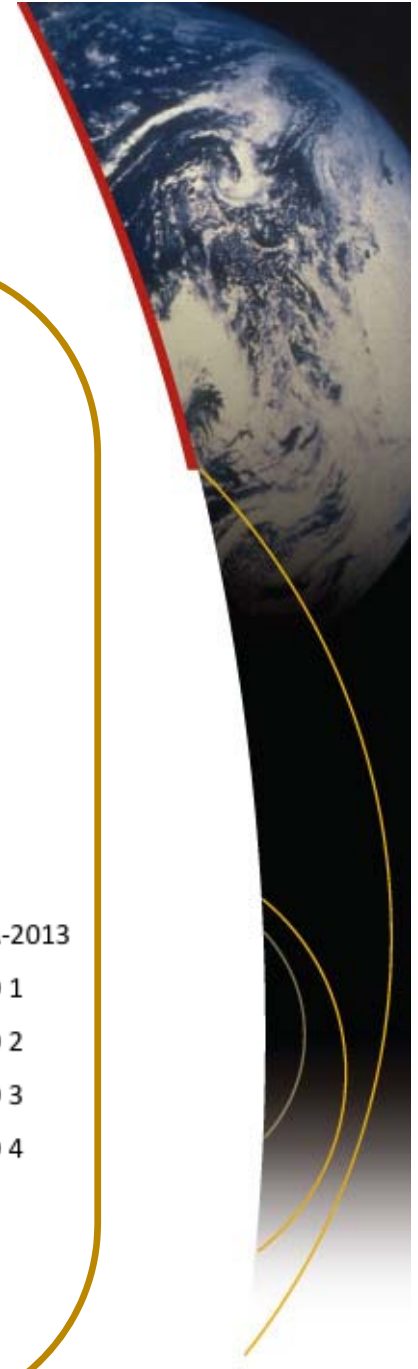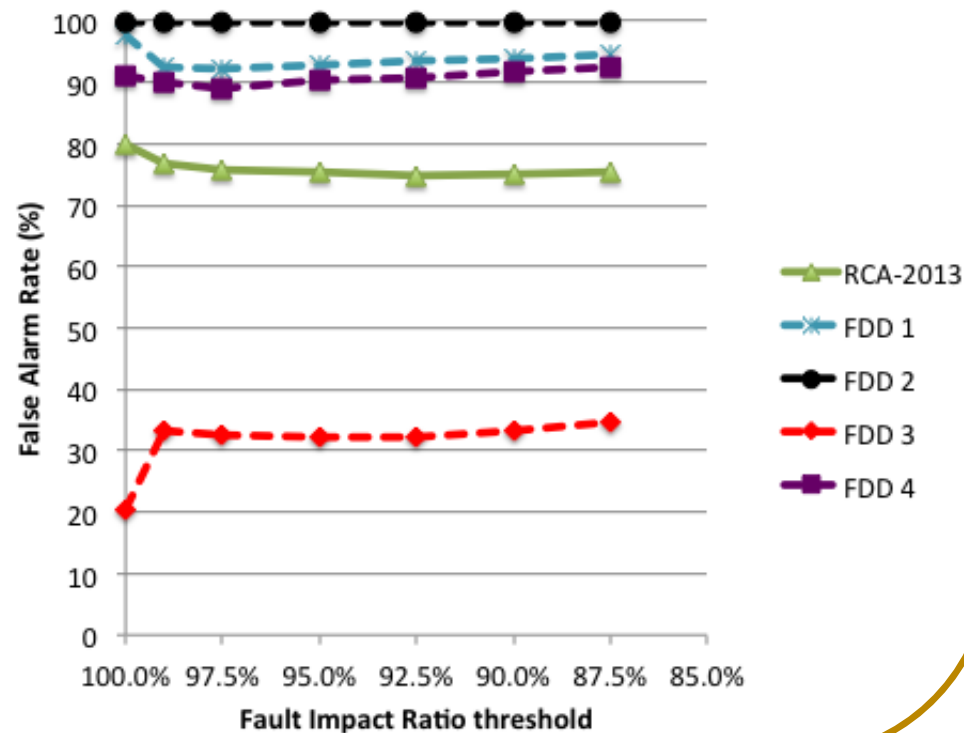
Example Evaluations

- Misdiagnosis
  - FDD correctly detects presence of a fault
  - Wrong fault is diagnosed
  - $FIR_{capacity}$ and FIR_{COP} treated separately (FIR_{COP} is below)
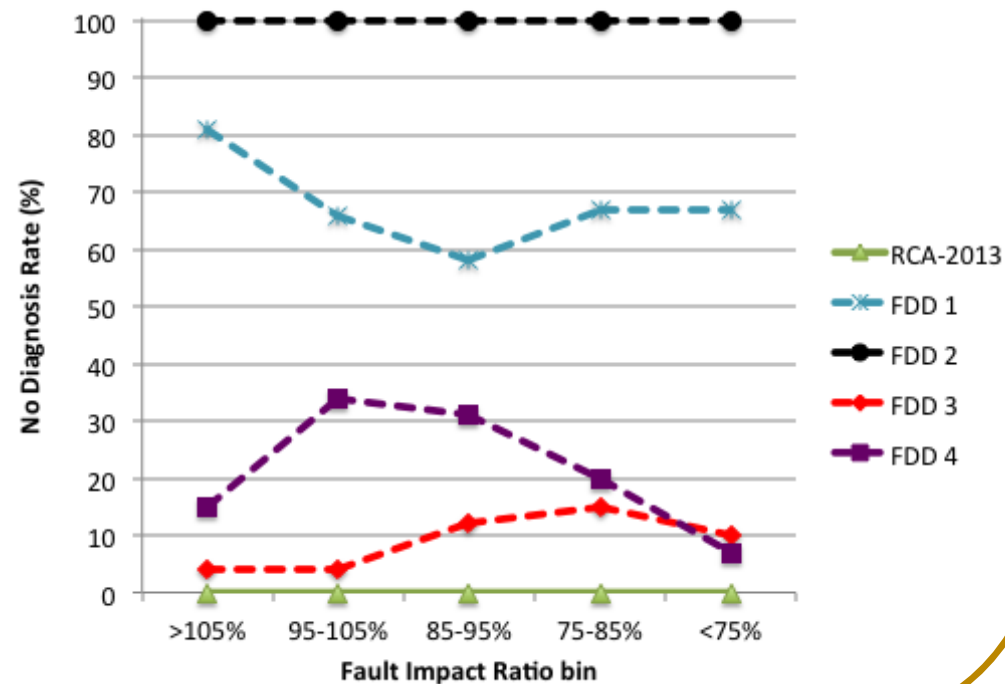
Example Evaluations

- Missed Detections
    - FDD report no fault
    - Fault is present
    - $FIR_{capacity}$ and FIR_{COP} treated separately (FIR_{COP} is below)
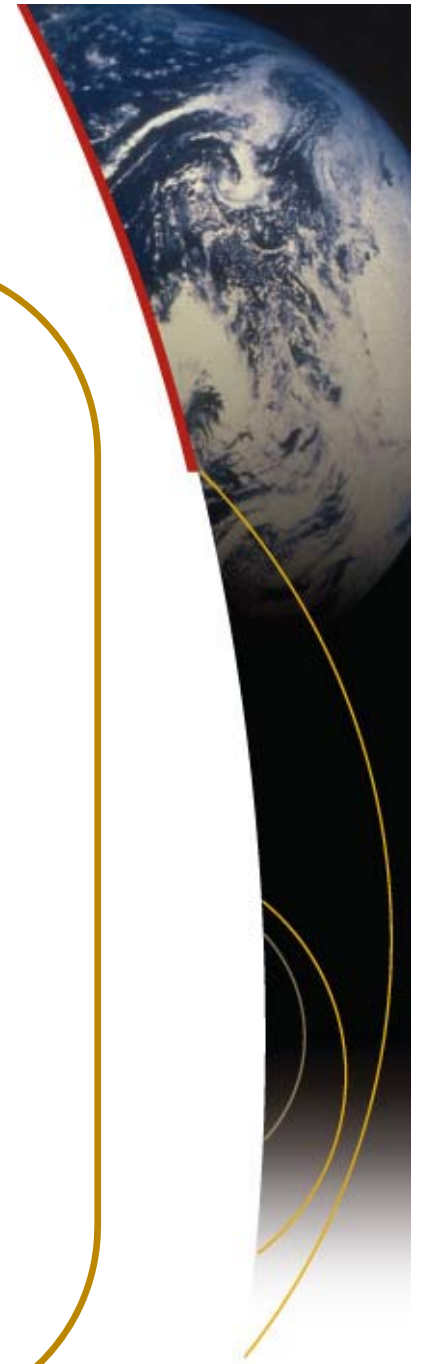
Example Evaluations

- No Diagnosis
    - FDD correctly detects fault
    - Cannot diagnose fault type
    - $FIR_{capacity}$ and FIR_{COP} treated separately (FIR_{COP} is below)

Example Evaluations

- Confusion plot for FDD 4

Confusion plot showing Actual Condition (rows) vs Protocol output (columns).

Actual Condition	NoF	UC	OC	EA	CA	NC	LL	VL	NoResponse	NoDiagnosis	TXV
NoF	3	0	0	48	0	2	0	0	40	6	1
UC	1	1	0	49	2	0	0	0	36	11	1
OC	0	0	2	50	0	1	0	0	42	5	0
EA	1	0	1	56	1	1	0	0	37	3	1
CA	0	0	0	32	24	1	0	0	36	7	0
NC	1	0	1	51	0	2	0	0	38	7	1
LL	3	0	0	49	0	0	0	0	40	7	1
VL	0	0	2	51	1	0	0	0	40	5	0

Example Evaluations

- Confusion plot for FDD 3

Performance Metric (in progress)

- Overall economic value of FDD tool
  - For specific application (tons, weather, loads...)

- Combine probabilities of:
  - FDD being applied (T_{amb})
  - Presence of fault type
  - Fault intensity

- Add costs of service
  - Varies as function of diagnosed fault type
  - Mystery: what to do with No Response & No Diagnosis

- Subtract savings from correct diagnoses
  - Reduced equipment wear over time
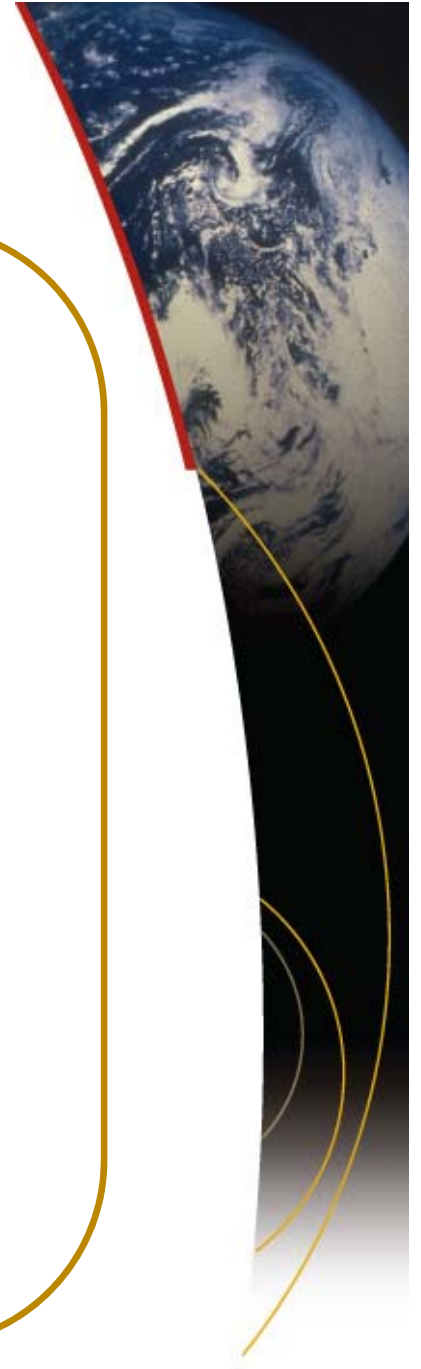 - Reduced energy use over time
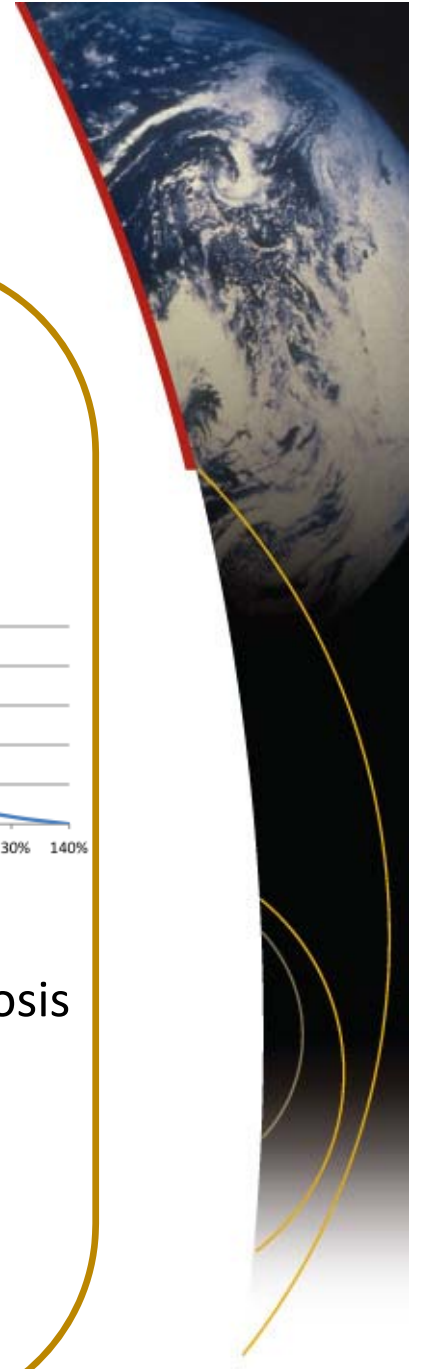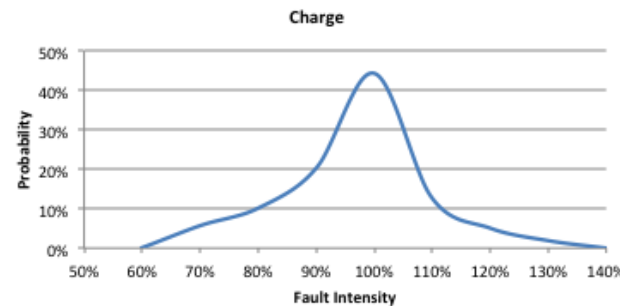
Conclusions

- FDD evaluation is necessary (performance variations)

- Simulation must be used (even input distribution)

- Current FDD may not perform as expected

- Fault prevalence is an important unknown

- Stay tuned for economic performance metric results
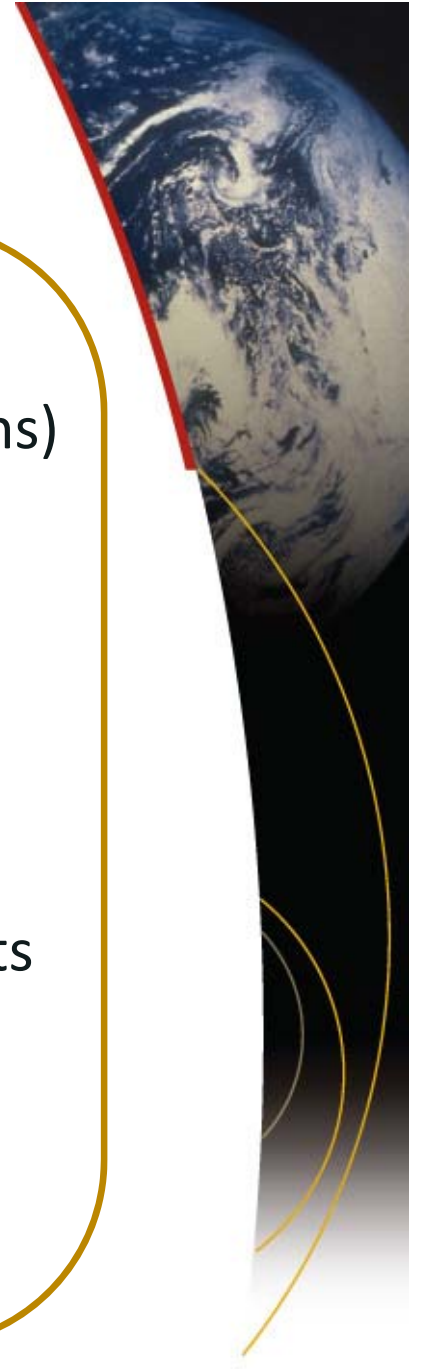
Thank you

- Questions

References

Cheung, H. and Braun, J.E., 2013a, Simulation of Fault Impacts for Vapor Compression Systems by Inverse Modeling Part I: Component Modeling and Validation, *HVAC&R Research*, vol. 19, no. 7: p. 892-906.

Cheung, H. and Braun, J.E., 2013b, Simulation of Fault Impacts for Vapor Compression Systems by Inverse Modeling Part I: System Modeling and Validation, *HVAC&R Research*, vol. 19, no. 7: p. 907-921.

Yuill, D.P. and Braun, J.E., 2013, Evaluating the performance of FDD protocols applied to air-cooled unitary air-conditioning equipment. *HVAC&R Research*, vol. 19, no. 7: p. 882-891.