Passive Thermal Session #2

Statistical Analysis of Thermal Analysis Margin

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Presented By

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Thermal & Fluids Analysis Workshop
TFAWS 2011
August 15-19, 2011
NASA Langley Research Center
Newport News, VA

Agenda

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- Mass/Power Impacts of Analysis Margins
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  - Trends versus thermal control type
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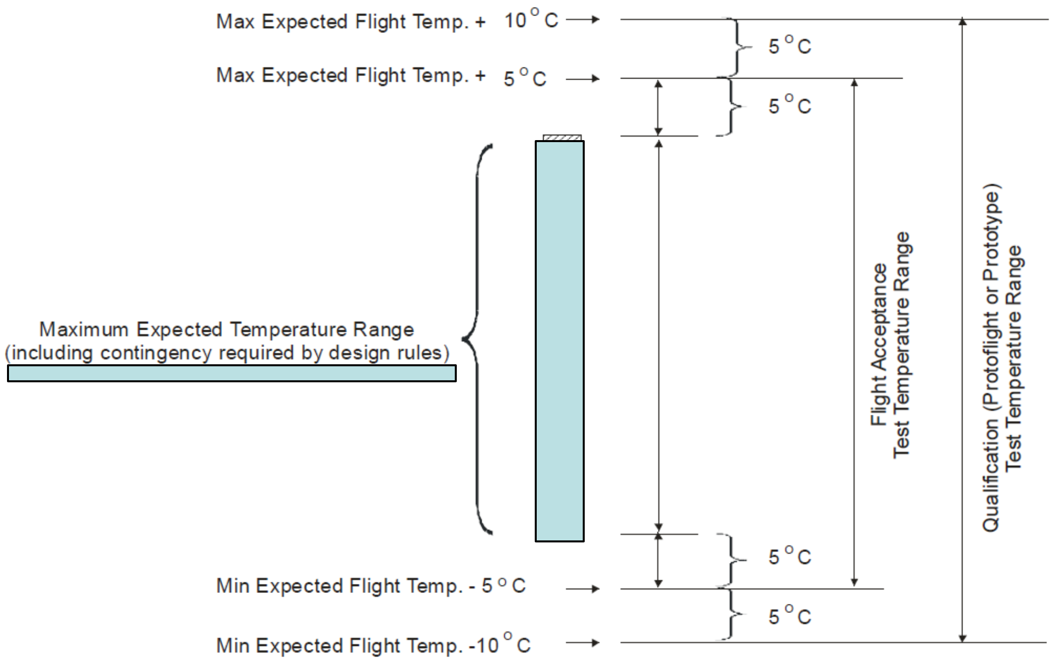
Introduction

- NASA Goddard Space Flight Center requires that each project demonstrate a minimum of 5°C margin between temperature predictions and hot and cold flight operational limits
  - Bounding temperature predictions include worst-case environment and thermal optical properties
- **Purpose of this work is to:**
  - Assess how current missions are performing against their pre-launch bounding temperature predictions
  - Suggest any possible changes to the thermal analysis margin rules



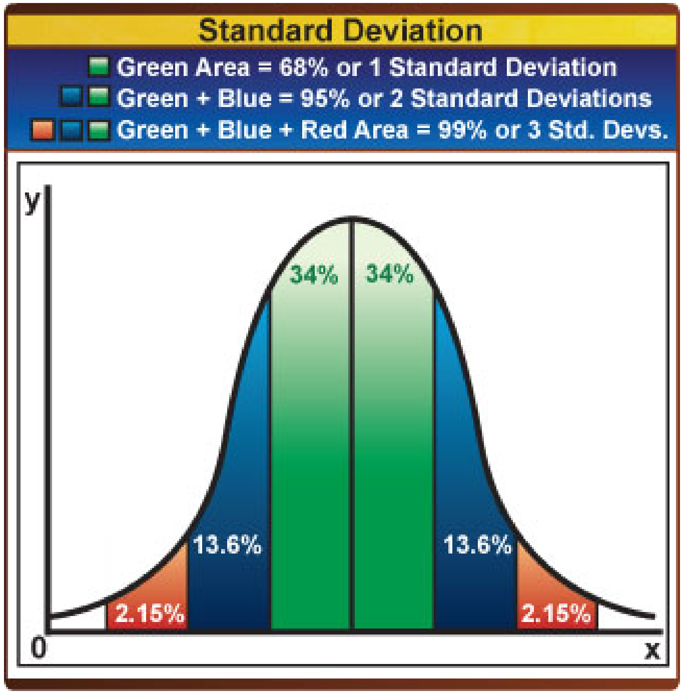
Mass/Power Impact of Analysis Margin

- 4 radiators on 3 missions used to assess impacts of electronics analysis margin on mass and power
  - LRO and GPM radiators are as-built sizes (both aluminum honeycomb panels with embedded CCHPs)
  - ATLAS radiators are design sizes + 20% contingency (both aluminum honeycomb panels, no CCHPs)
- Radiators sizes can be increased by up to 8% by adding 5C analysis margin
- Survival heater power can be increased by up to 20% by adding 5C analysis margin

Parameter	LRO ITP	GPM AM	ATLAS +Y	ATLAS +X
Orbit	LLO	LEO	LEO	LEO
View	Zenith Solar	Earth, Albedo	Earth, Albedo	Earth, Albedo, Solar
Mass	14.7 kg	10.1 kg	18.4 kg	2.2 kg
Load	356 W	350W	209W	46W
Extra Mass for 5C Margin	0.27 kg per 100W load	0.23kg per 100W load	0.67 kg per 100W load	0.43 kg per 100W load
Extra Surv Heater Power for 5C Margin	4.1W per 100W load	4.8W per 100W load	4.1W per 100W load	6.0W per 100W load

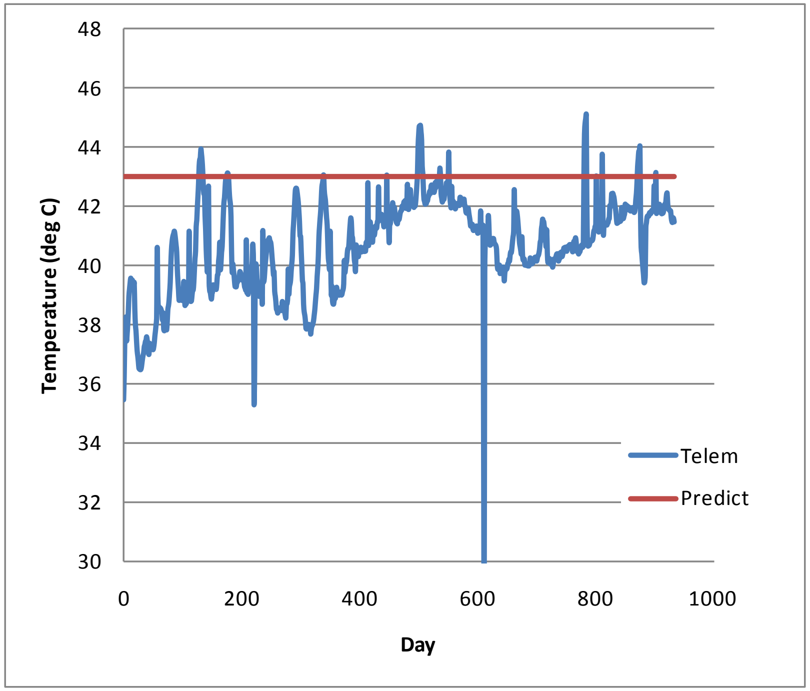
Description of Method

- **Pre-launch thermal predictions were obtained for each mission**
- **Thermal telemetry was received from the operations team for each temperature sensor in whatever format was available**
  - Max temperature per orbit, day or week
  - Only looking at max temperatures because there was no easily available telemetry on heater duty cycles in cold cases
- **Predicted max temperatures were compared against observed peak temperatures using three thresholds**
  - Max Temperature – hottest measurement ever on a given temperature sensor
  - 99% Max Temperature – disregards the highest 1% of measurements (3σ)
  - 95% Max Temperature – disregards the highest 5% of measurements (2σ)
- Temperature sensors are grouped in different ways to generalize these results



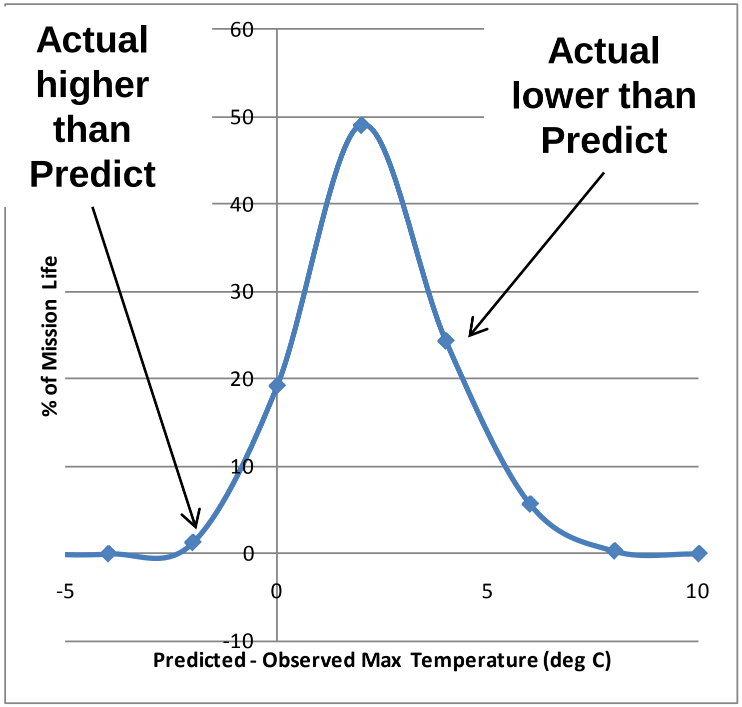
Simplified Analysis Example

- Example analysis uses GLAST RWA 1 temperature sensor



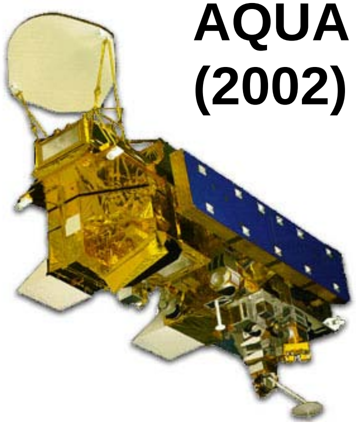
Avg = 40.7°C
σ = 1.6°C

Predict = Avg + 1.4σ

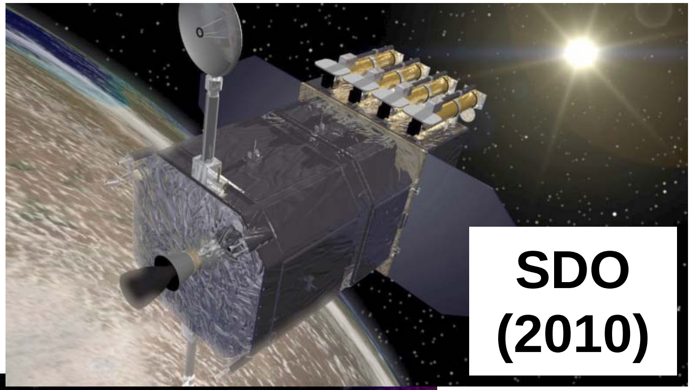


- “Predicted – Observed Max Temperature” curve shows the percentage of mission life spent at each 2°C wide temperature band, with 0°C corresponding to the hottest pre-launch predict
  - GLAST RWA1 spent 19% of its’ days on orbit with a max temperature equal to the hottest pre-launch predicts
  - Only 1% of the days spent on orbit had temperatures up to 2°C above the hottest pre-launch predicts

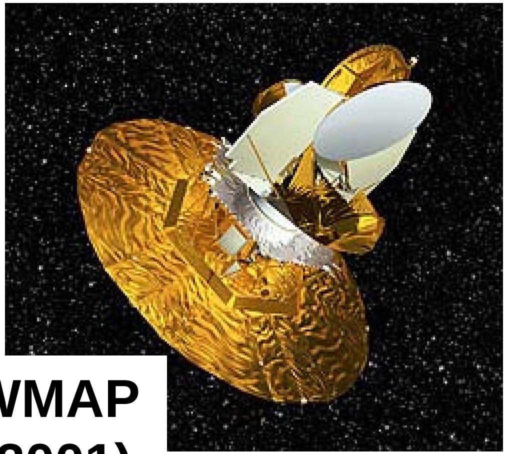
Analyzed Missions (1 of 2)



AQUA (2002)



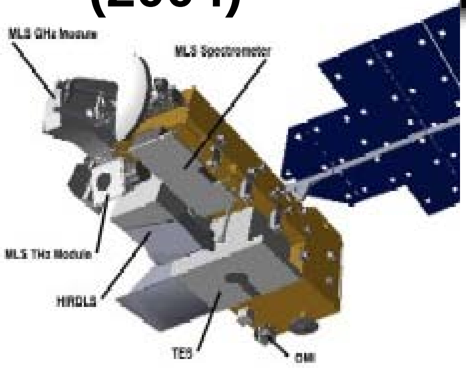
SDO (2010)

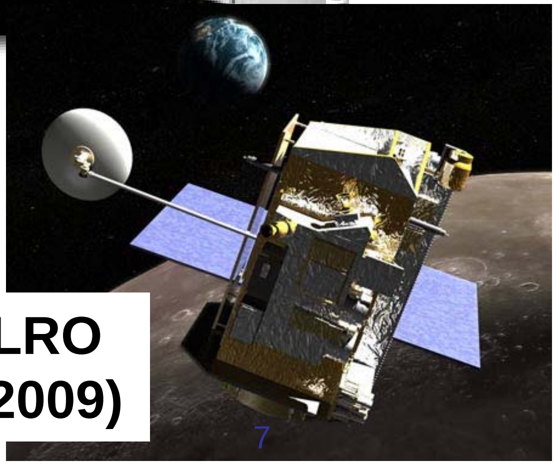


WMAP (2001)

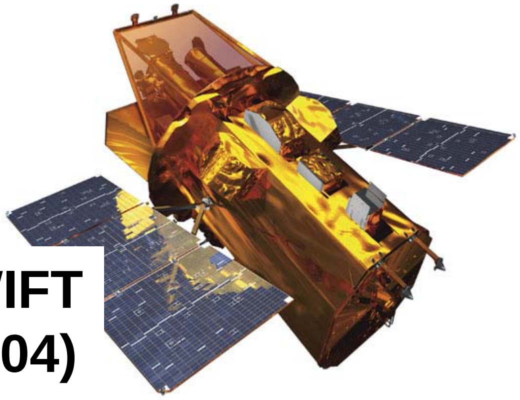
GLAST (2008)

AURA (2004)





LRO (2009)



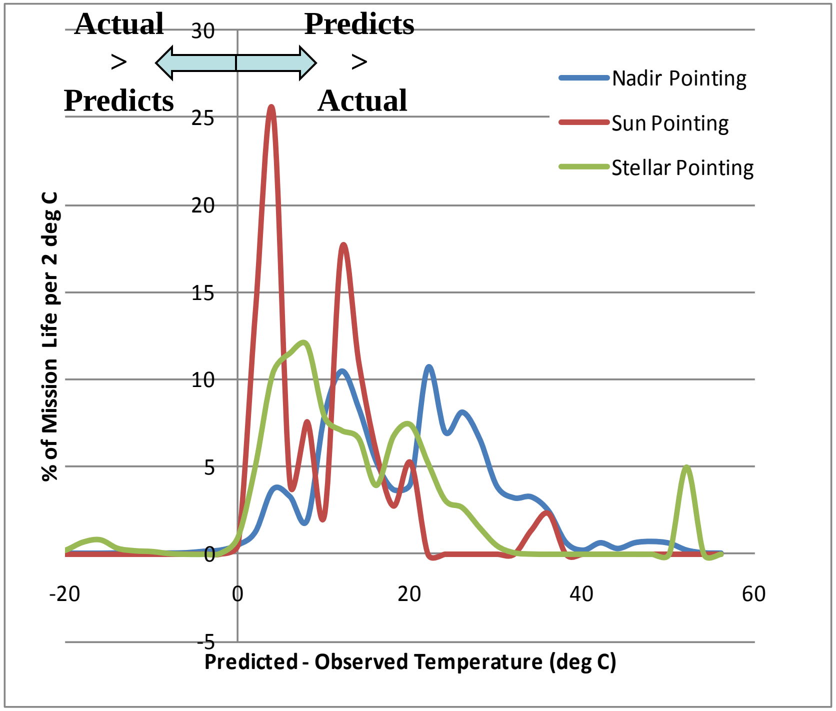
SWIFT (2004)

Analyzed Missions (2 of 2)

Param.	AQUA	AURA	GLAST	LRO	SDO	SWIFT	WMAP	Total
Orbit	LEO	LEO	LEO	LLO	GEO	LEO	L2	
Pointing	Nadir	Nadir	Stellar	Nadir	Solar	Stellar	Solar	
# of Time Steps	456 weeks	362 weeks	932 days	536 days	296 days	34089 orbits	3389 days	
# of Sensors	57	51	25	34	19	15	8	209
Structure	18	23	0	12	0	0	8	61
Actuators	2	0	2	4	0	2	0	10
Arrays	7	6	1	2	0	0	0	16
Batteries	2	2	2	1	1	1	0	9
Power Elect.	3	6	2	2	0	1	0	14
CDH	7	6	3	3	2	2	0	23
Comm. Elect.	2	4	4	2	4	1	0	17
IRU	2	2	1	2	2	3	0	12
RWA	12	0	4	4	8	3	0	31
Star Trackers	2	2	6	2	2	2	0	16

Results Vs Thermal Environment

- Sun- and Nadir-pointing data shows that the hot predicts bound the on-orbit data
- Stellar-pointing data shows a small occurrence of on-orbit data ~18°C above the hottest predict
  - When GLAST Solar Array is neglected, 0.1% of the Stellar-pointing data is above the max predict
- There is no correlation between the appropriate analysis margin and the thermal environment



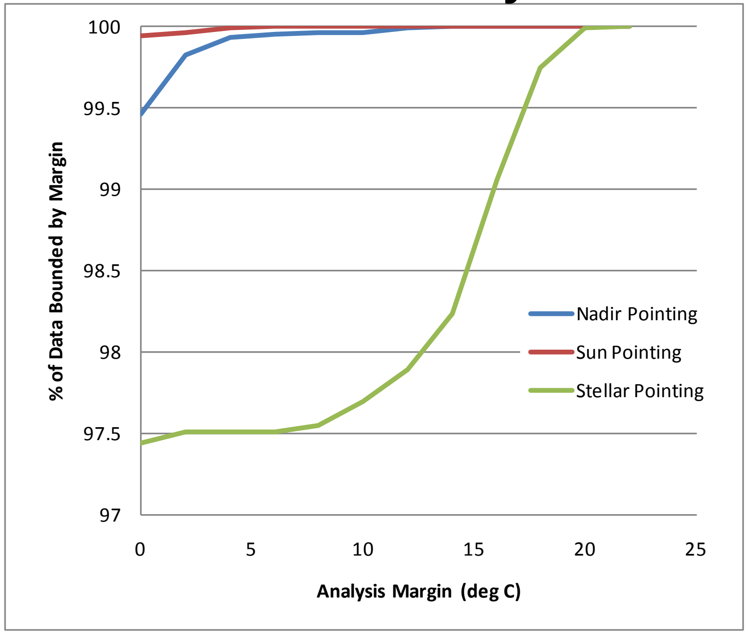
Parameter	Nadir-Pointing	Sun-Pointing	Stellar-Pointing
% of Mission Life Above Predicted	0.3%	0%	2.6%
Analysis Margin, 99%	0°C	0°C	16°C
Analysis Margin, 95%	-4°C*	0°C	-1°C*

(*) Negative analysis margin indicates that the hot bounding case over-predicts the max temperature 99 or 95% of the time

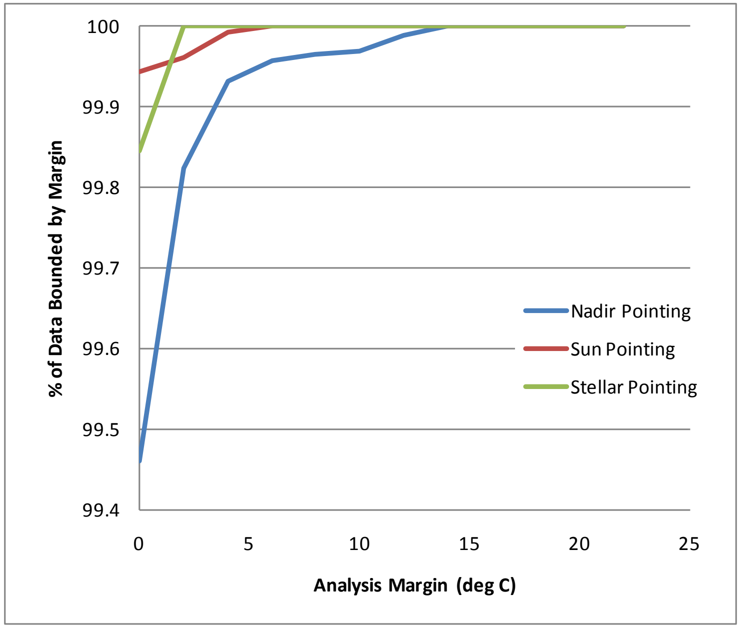
Analysis Margin Vs Thermal Environment

- Plots show the percent of data points bounded by a given analysis margin (2 temperature sensors at 5 time steps = 10 data points)
- When GLAST Array is neglected, >99% of all data points are bounded with no need for analysis margin, independent of environment (Arrays make up 2.5% of total data)
- This does not mean that individual groupings of data do not need analysis margin

Includes Arrays

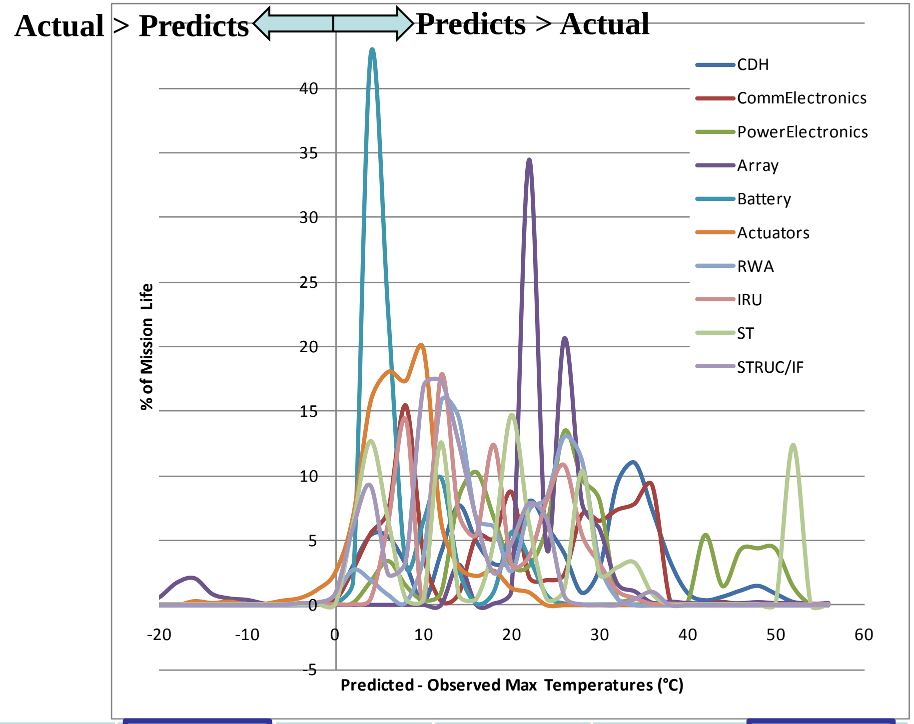


Ignores Arrays



Results Vs Component Type

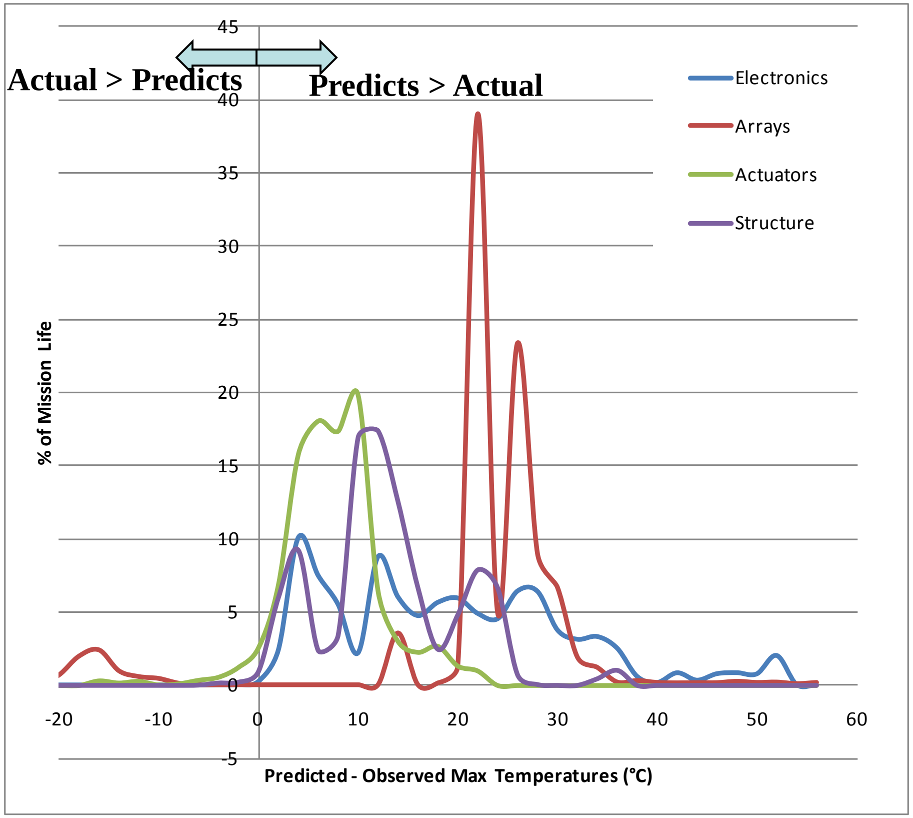
- **Similar components were compared, including data from multiple missions**
- **Trends indicate that these should be further grouped into thermal control types**
  - **Electronics – Heat dissipated through a controlled TCS**
  - **Passive structures – No heat**
  - **Solar Arrays – Direct coupling to varying sink**
  - **Actuators – Poor thermal path, varying views to sink**



Parameter	CDH	Comm Elec.	Power Elec.	Array	Batt.	Act.	RWA	IRU	ST	Struc
% of Mission Life Above Predicted	0%	0%	0%	5.9%	0%	3.1%	0.1%	0%	0%	0.4%
Analysis Margin, 99%	0°C	0°C	-3°C*	18°C	-1°C*	8°C	0°C	-4°C*	0°C	0°C
Analysis Margin, 95%	-2°C*	-3°C*	-6°C*	15°C	-2°C*	0°C	-4°C*	-6°C*	-2°C*	-2°C*

Results Vs Thermal Control Type

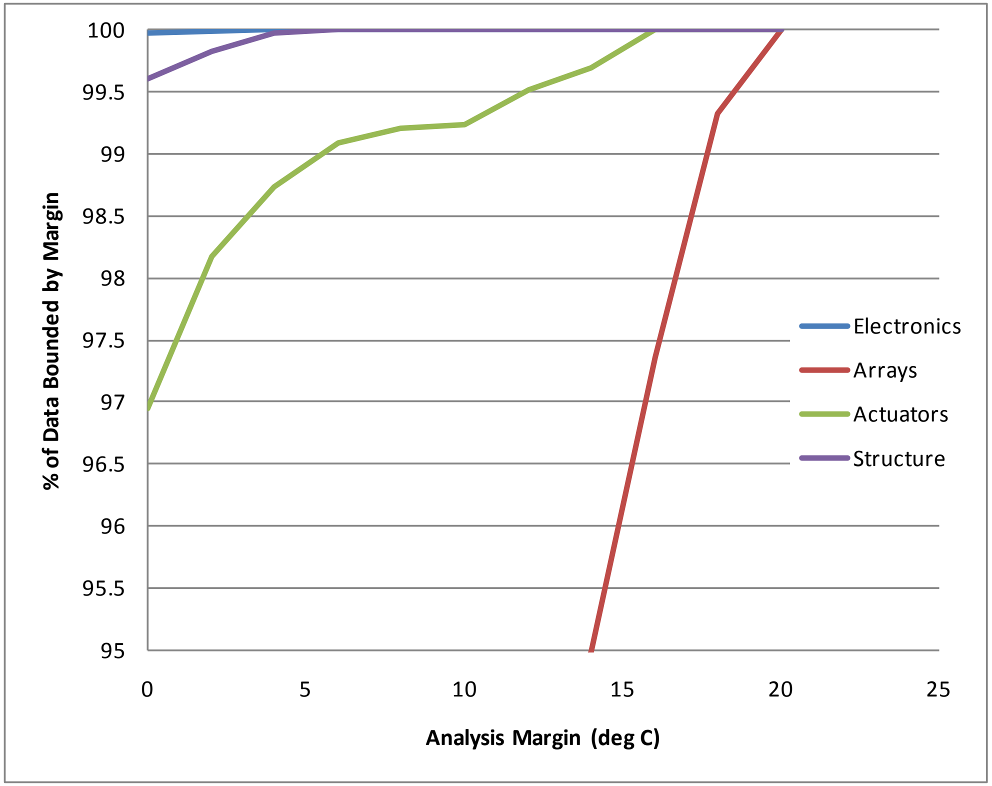
- **Electronics and structure have little to no observed data that exceeds the max predicted temperature**
- **Actuator temperatures exhibit a bell curve centered around observed temperatures 8°C below predicted max temperatures, but with 3% of data exceeding the predicted max**
- **Solar arrays mostly run 20°C below max predicts, but the GLAST solar array provides data substantially above the predicted max**



Parameter	Electronics	Solar Arrays	Actuators	Structure
% of Mission Life Above Predicted	0%	5.9%	3.1%	0.4%
Analysis Margin, 99%	-1°C*	18°C	10°C	0°C
Analysis Margin, 95%	-3°C*	15°C	0°C	-2°C*

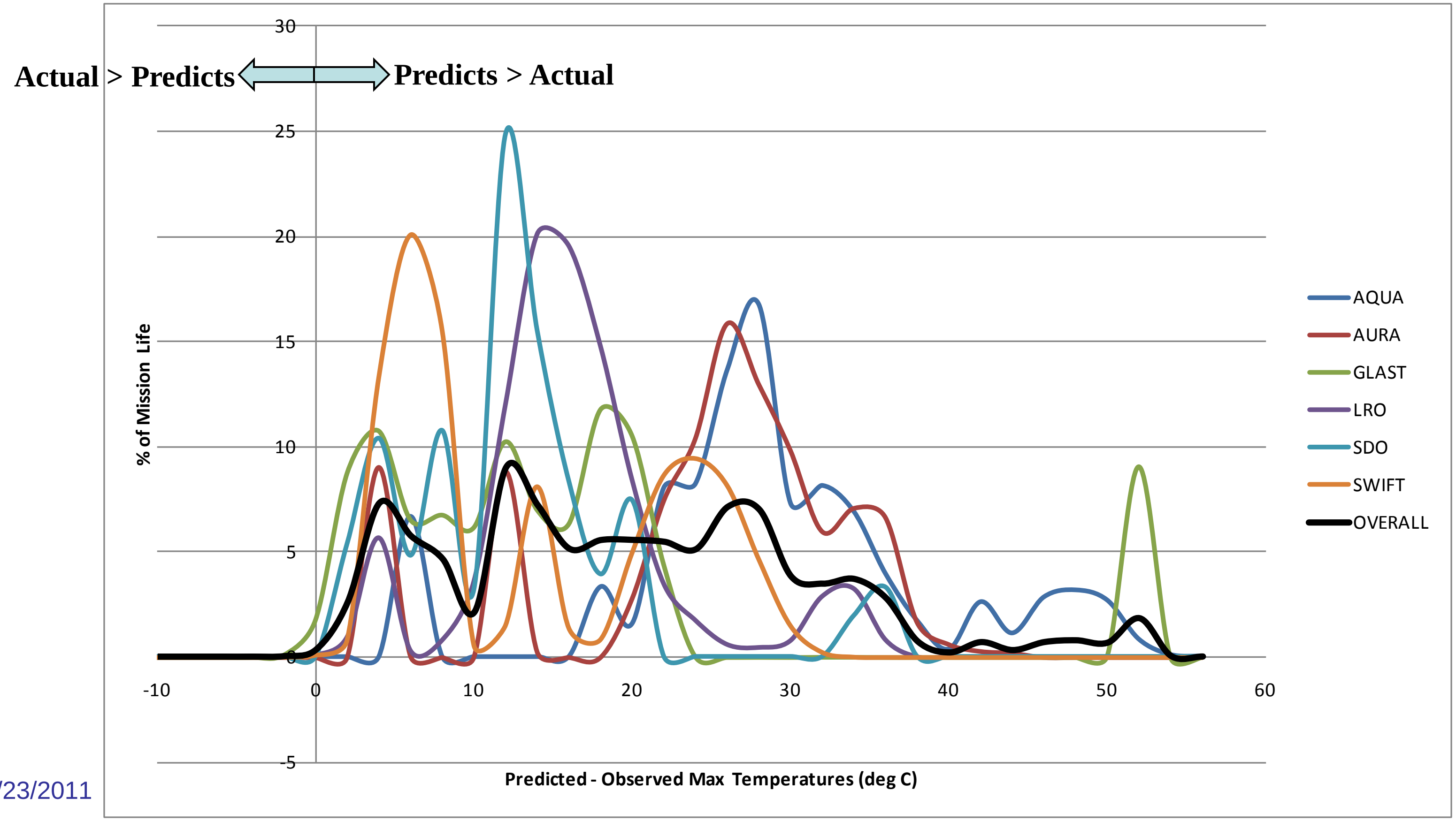
Analysis Margin Vs Thermal Control Type

- Plots show the percent of data points bounded by a given analysis margin (2 temperature sensors at 5 time steps = 10 data points)
- Array data is skewed by the single solar array temperature sensor for GLAS
  - If GLAS array data is neglected, Array line is at 100% for any analysis margin
- Actuators show a need for some analysis margin
- Electronics and structure are largely sufficient without analysis margin



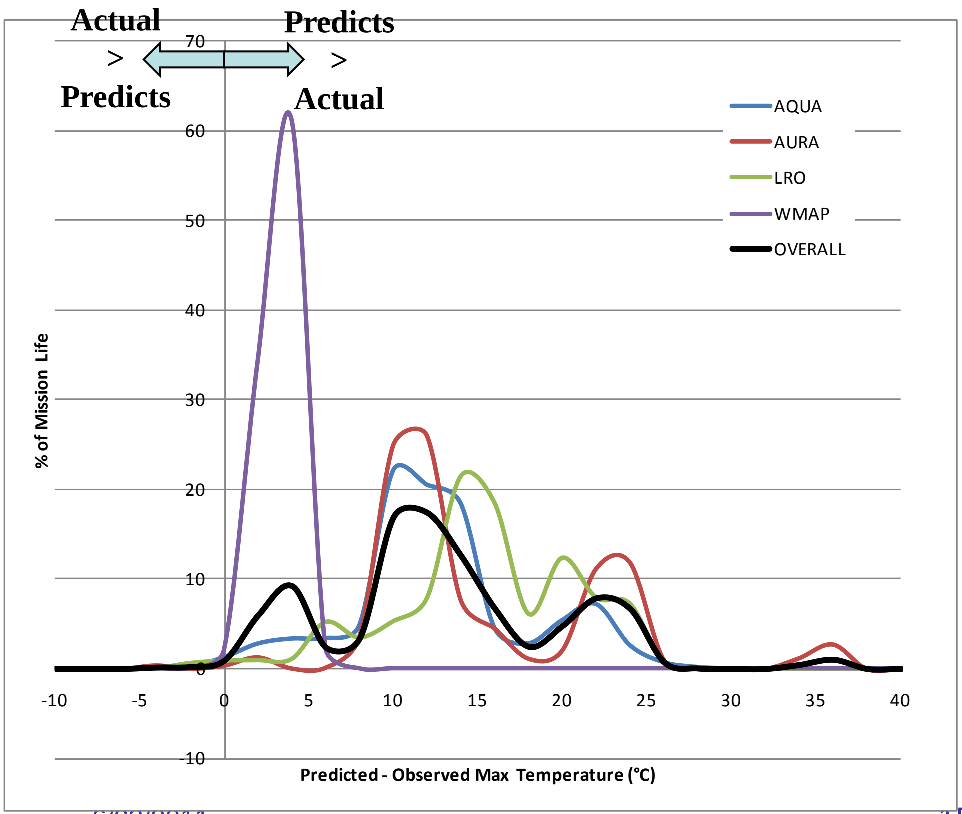
Recommended Margins: Electronics

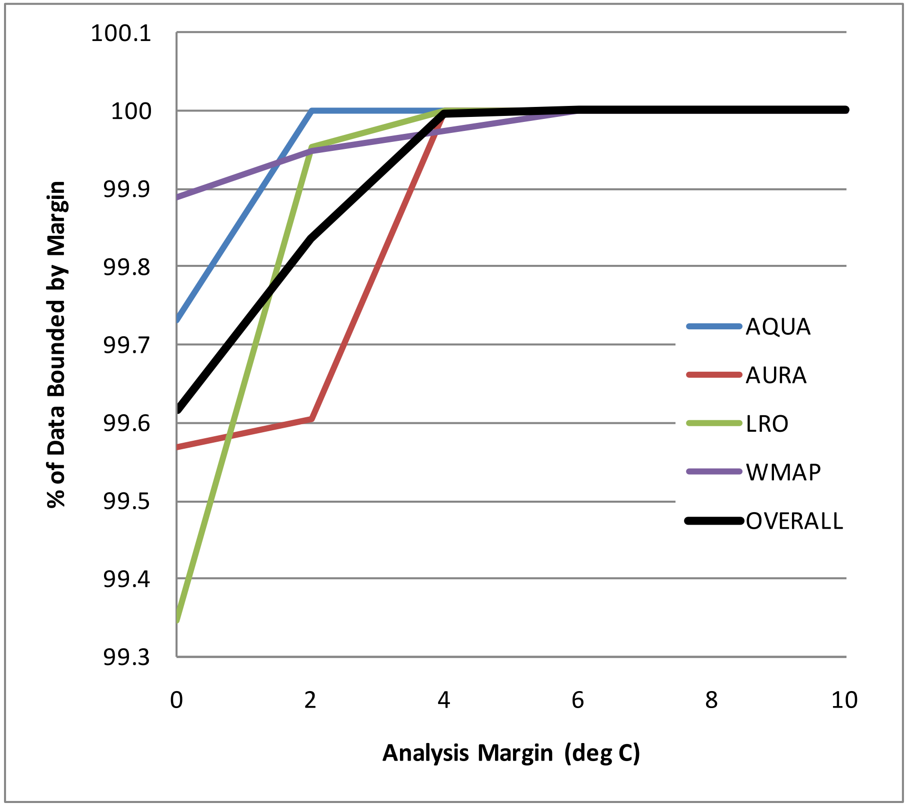
- **For electronics, all data is bounded without the need for analysis margin except for 0.02%**
- **OBSERVATION – Based on the data presented, the required analysis margin for electronics could be reduced from 5°C to 0°C at launch. More margin may be needed during the design process.**



Recommended Margins: Structure

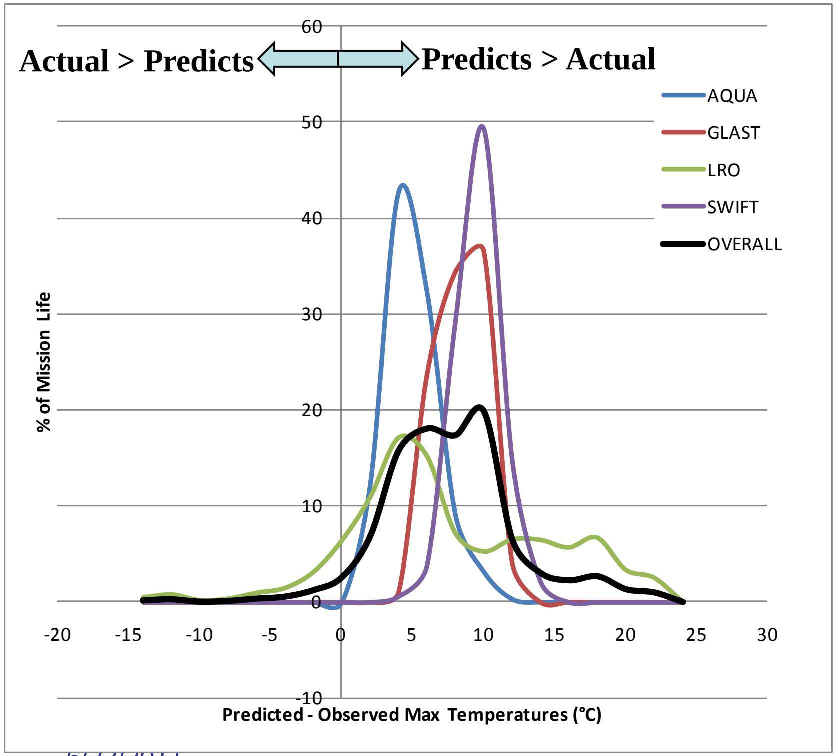
- For passive structures, >99% of all data is bounded without the need for analysis margin
- OBSERVATION – Based on the data presented, the required analysis margin for passive structures could be reduced from 5°C to 0°C at launch. More margin may be needed during the design process.

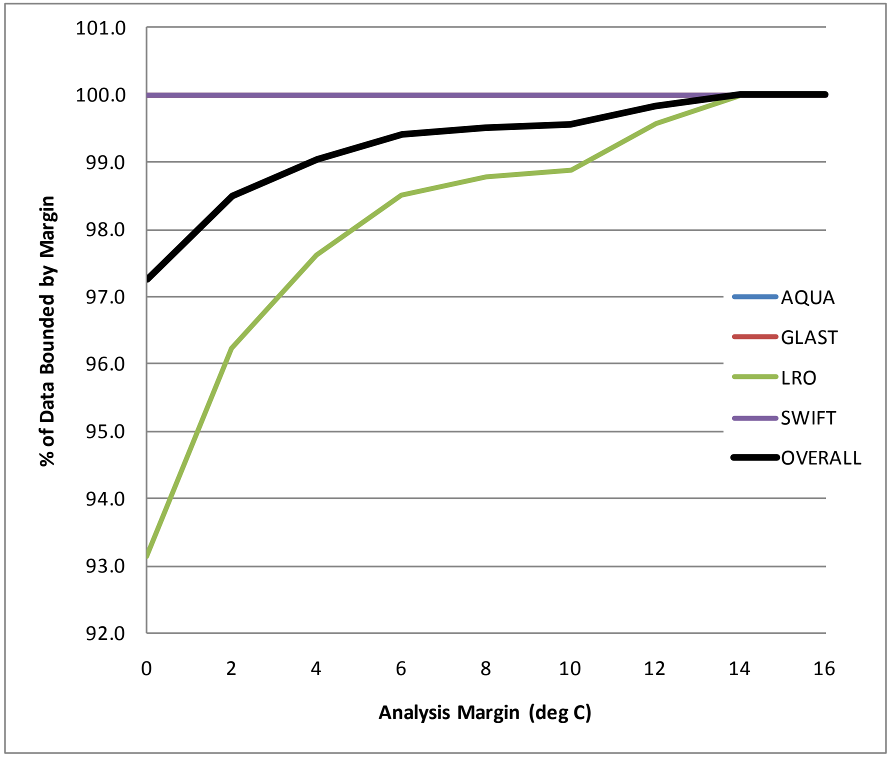




Recommended Margins: Actuators

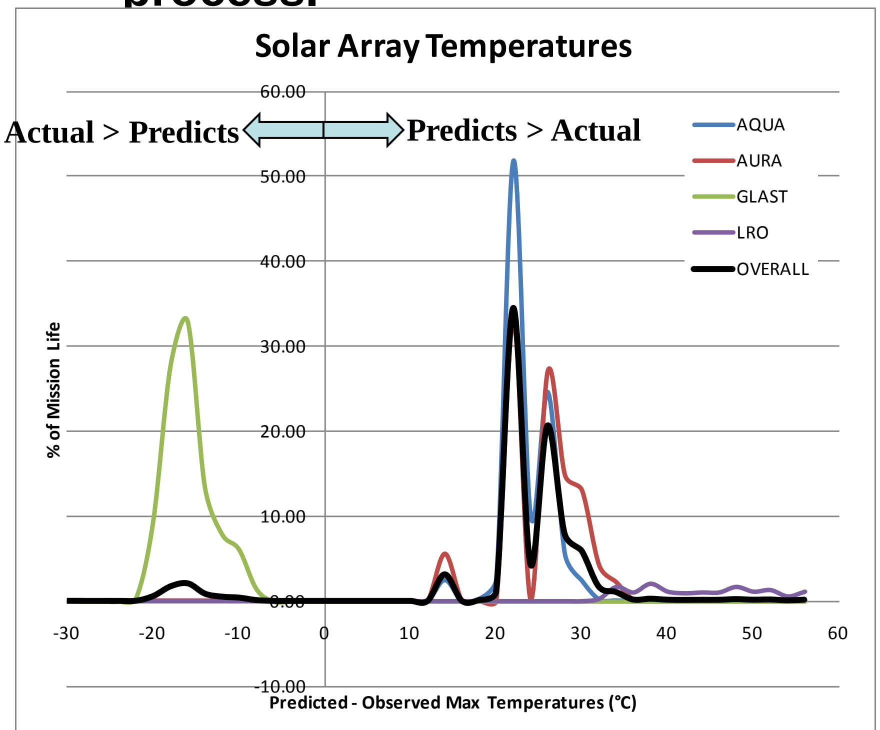
- All 4 LRO actuators are the only that ever exceed max predicts
- For actuators, >97% of all data is bounded without the need for analysis margin
- OBSERVATION – Based on the data presented, the required analysis margin for actuators could be raised from 5°C to 10°C (99% confidence), but allow higher-risk missions to use 0°C analysis margin (>95% confidence) at launch. More margin may be needed during the design process.

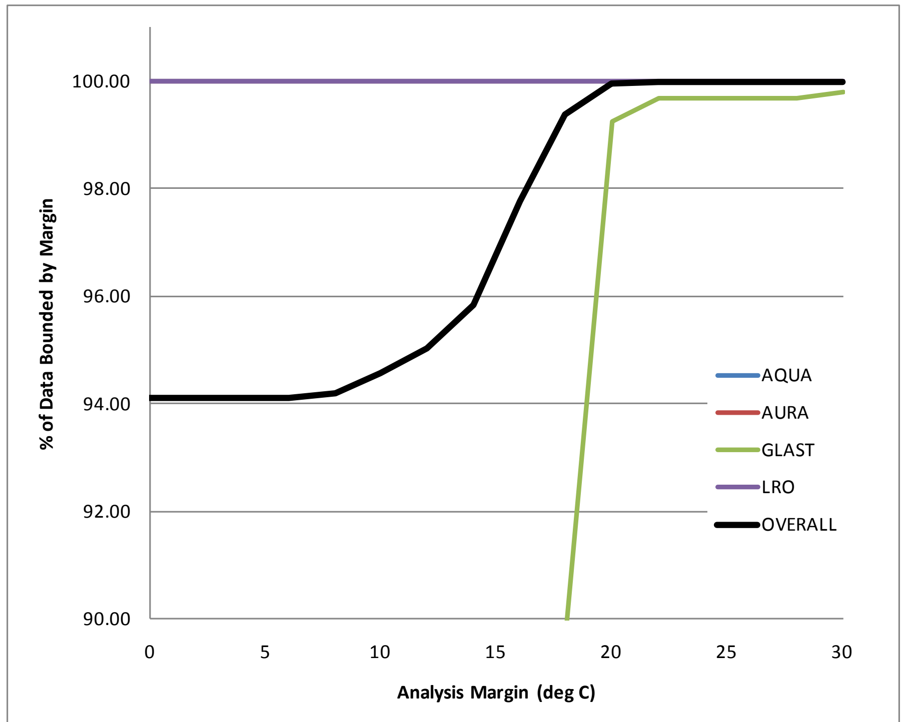




Recommended Margins: Solar Arrays

- **GLAST solar arrays ran ~20°C above predicts, but still had 15-20°C margin versus hot operational limits**
- **For arrays, 94% of all data is bounded without the need for analysis margin**
- **OBSERVATION – Based on the data presented, the required analysis margin for actuators could be raised from 5°C to 18°C (99% confidence), but allow higher-risk missions to use 12°C analysis margin (>95% confidence) at launch. More margin may be needed during the design process.**





Conclusions

- It was shown that thermal analysis margin has real and noticeable impacts on system resources (mass and power)
- Pre-launch temperature predictions were compared against on-orbit telemetry for multiple recent missions
- No correlation was found between the accuracy of predictions and the thermal environment of the mission
- A correlation was found between the component type and the analysis margin needed to bound an appropriate amount of flight data
- New analysis margins were suggested based on component type
  - Internal electronics and passive structure
  - External components exposed to the environment
  - Actuators

Future Work

- Identify more missions that can provide telemetry to expand the existing data set, with focus on:
  – Solar arrays
  – Actuators
- Investigate the possibility of comparing predicted versus observed heater power to see if the margins need to change between the hot and cold bounding temperature predictions