P4.1: ABI Flight Performance Predictions Based on Prototype Model (PTM) Test Results

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Synopsis

This paper takes the measured performance of the ABI PTM and predicts the on-orbit performance of the ABI flight instruments, showing significant performance margin in many areas including coverage, SNR, NEdT, dynamic range, MTF, edge response, spatial response uniformity, and image quality.

1. Introduction

The next generation Advanced Baseline Imager (ABI), a NASA administered and NOAA funded program designed and built by ITT Geospatial Systems, will fly on the GOES-R geostationary weather satellite later this decade. It is a 16-channel imaging radiometer that provides significantly increased capabilities over the current operational GOES Imager (significantly more channels, higher resolution, and faster image repetition rates). Its mission is to measure earth radiant and reflective solar energy at moderate spatial and spectral resolution and high temporal and radiometric resolution. After processing with ITT's algorithms, the calibrated, geo-located images will be used to produce a wide variety of weather data products – including monitoring of rapidly changing weather. The accuracy of these products depends heavily upon the SNR and spatial content of these images.

The ABI prototype model (PTM) is a flight-like instrument built to qualify the ABI design and the assembly, integration and test procedures. It has successfully completed the full suite of environmental tests: vibration, EMI, and thermal-vacuum. The ability of the instrument to collect the scan mode 3 and 4 coverage scenarios has been demonstrated, along with the ability to collect custom scenes using custom timelines. The performance has been measured for all requirements, including SNR, dynamic range, spatial response (MTF, edge response, and spatial response uniformity), and image quality. This measured performance enables ITT to predict the worst case on-orbit performance for the flight instruments. These predictions show significant margin in many areas.

2. ABI Design Summary

The ABI instrument consists of three units: Sensor Unit (SU), Electronics Unit (EU), and Cryocooler Control Electronics (CCE), as shown in Figure 1. All electronics are fully redundant. The EU contains both Side 1 and Side 2 electronics in a single chassis whereas there is one CCE for each side.

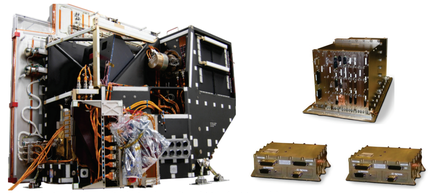


Figure 1. PTM Sensor Unit, Electronics Unit and CCEs (not to scale)

The ABI two-mirror scanner is shown in Figure 2. This scanner permits the instrument to collect a full disk image in five minutes (Scan Mode 4) as well as the complex Scan Mode 3 scenario (the parts of which are shown in Figure 3):

- Full Disk image every 15 minutes
- CONUS image every 5 minutes
- Mesoscale (storm watch) image every 30 seconds
- Maximum swath-to-swath interval of 30 seconds

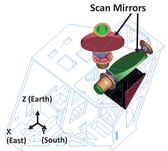


Figure 2. ABI Two-Mirror Scanner

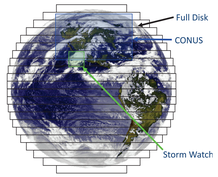
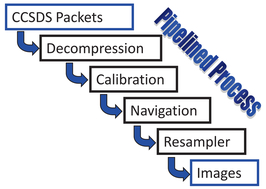


Figure 3. Scan Mode 3 Image Types

The ground processing algorithms (GPAs) are a key part of the ABI system's performance. Most ABI requirements are levied against the final calibrated, geo-located pixel image. ABI's GPAs were developed in conjunction with the instrument in a system-level optimization to maximize the quality of the images delivered to the end users. The ground processing is shown in Figure 4. All algorithms have been demonstrated to run on real, off-the-shelf hardware in real time.

- Decompression: extracts science data from the CCSDS packets and reverses the lossless compression to output raw detector samples in counts
- Calibration: Uses spacelook and on-orbit calibration target data to radiometrically calibrate each detector sample
- Navigation: Uses star observations in conjunction with scan encoder data and spacecraft-provided orbit and angular rate data to calculate the location where each detector sample was collected
- Resampler: Resamples the calibrated, navigated detector samples to produce pixels on the GOES-R fixed grid.

The resampler uses an easily implemented 4x4 kernel but the algorithm to generate the weights is unique to ITT.



ABI's design ensures the highest quality weather products

Figure 4. ITT's Ground Processing Algorithms Deliver Calibrated, Geo - located Images in Real Time on Real Hardware

3. ABI Flight Model Performance Predictions

There are seven key groups of requirements that ensure the ABI images will generate excellent weather data products:

- ✓ Coverage
- ✓ Spectral Response
- ✓ Spatial Response
- ✓ Image Quality
- ✓ Radiometric
- ✓ Dynamic Range
- ✓ Calibration Accuracy

Measured PTM performance has been adjusted for flight instrument component performance (e.g. optical throughput) and on-orbit effects (e.g. scattered sunlight) to predict the operational performance of the ABI flight instruments. These results show ABI will meet its requirements with margin (significant margin in many cases). Predictions in this paper are current worst-case estimates (CWE). They assume worst case performance for all components and hence represent a lower bound. Actual performance should be better.

3.1 Coverage

The ScanMode 3 and 4 coverage requirements are easily met with ITT's advanced scanner and optimized timelines, as shown in Table 1. Furthermore, custom timelines can be defined and uploaded at any time in the operational life – a capability ITT has used very successfully to automate the PTM testing. All image-to-image interval variation has been demonstrated to be more than 1000x less than the requirements.

Table 1. Temporal Data Products Improved by Consistent Image - to - Image Intervals

Timeline	Requirements				Measured Variation
	Scene	Quantity	Interval	Variation	
Scan Mode 4	Full Disk	1	300 s	±5 s	±0.0 s
Scan Mode 3	Full Disk	1	900 s	±30 s	±0.0 s
	CONUS	3	300 s	±30 s	±0.0 s
	Meso	30	30 s	±5 s	±0.0 s

3.2 Spectral Response

ITT has developed a very accurate method of combining component level spectral response measurements to predict the system-level spectral response. This was demonstrated on the PTM and validated by an end-to-end spectral response test using NIST's SIRCUS.

3.3 Spatial Response

The resolution of the ABI channels is frequently referred to as 0.5-km, 1-km, and 2-km. This is a handy, easily understood shorthand but what it actually means is the pixel spacing at nadir, not really the resolution. Resolution is defined by the modulation transfer function (MTF) requirements, which are one of three spatial response requirements that ensure the ABI images are sharp and the data products are free from spatial response artifacts.

- MTF: ensures sufficient detail
- Ringing: limits the overshoot and undershoot at sharp edges in the image
- Spatial Response Uniformity: ensures that multi-channel data products do not contain artifacts due to differences in the spatial response of the channels utilized

The MTF requirement ensures the images contain sufficient detail. ABI meets the MTF requirements with margin by design. We tune our resampler to deliver spec compliant imagery. The north-south (NS) and east-west (EW) CWE MTF performance is shown in Figure 5. This is the system performance for the image pixels averaged over all sample-to-edge and pixel-to-sample phases.

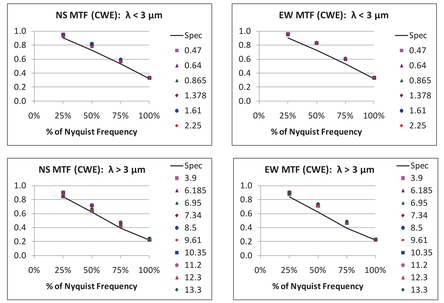


Figure 5. MTF Performance Ensures Higher Resolution Images

In Earth imagery, there are often regions with abrupt transitions (e.g. land/water boundaries). In an attempt to boost high frequencies to meet the MTF requirements, a typical resampler can create significant overshoot at this edge. That produces artifacts in the data products. With the ABI resampler the ABI system has negligible overshoot. It is compliant to the 2% overshoot requirement with significant margin, as shown in Figure 6, thus ensuring the highest quality imagery even at sharp transitions.

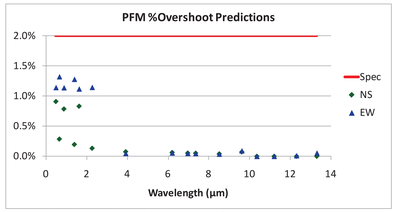


Figure 6. Minimizing Overshoot Minimizes Image Artifacts

The most challenging of the spatial response requirements is spatial response uniformity. Many weather products are formed by combining images from two (or more) channels. But even if all channels meet the MTF requirement, that does not mean they have they same spatial response. The physics driving the spatial response varies significantly across the wide wavelength range of ABI (0.47 –13.3 µm). ITT is able to tune the resampler kernel to achieve uniformity across all reflective channels and all emissive channels, as demonstrated by the compliance shown in Figure 7. Note that in the interest of space we have collapsed this two dimensional comparison into a linear plot of just the maximum and minimum non-uniformities.

This spatial response uniformity requirement applies not just to the standard resolution images but also to the downsampled images. The 0.64 µm channel is a 0.5-km channel. In order to form multi-channel products with the 0.47, 0.86, and 1.61 µm channels it is necessary to downsample it to a 1-km pixel spacing. And all four channels have to be downsampled to a 2-km pixel spacing in order to form products with the 1.38 and 2.25 µm channels. A simple area average, while great for boosting SNR, will result in a significantly different spatial response than the other 1-km channels. ITT provides resampler kernels for all downsampling operations, ensuring spatial response uniformity is maintained.

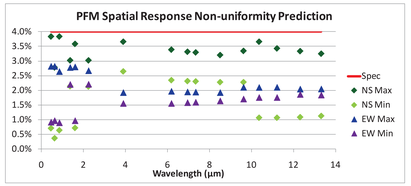


Figure 7. Multi-Channel Data Products Improved By Uniform Spatial Responses

3.4 Image Quality

As anyone who has observed imagery knows, there is more to a quality image than just MTF. One needs to avoid visual artifacts such as striping. That is the purpose of the four ABI image quality requirements:

- Pixel-to-Pixel Repeatability
- Swath-to-Swath Repeatability
- Image-to-Image Repeatability
- Channel-to-Channel Repeatability

The pixel-to-pixel and swath-to-swath requirements are against the specified NEdN – i.e. the non-repeatability must be less than the noise. The image-to-image and channel-to-channel requirements are against a 0.2K limit, which is twice the specified noise level for most emissive bands (but only 67% of the noise level for the 13.3 µm channel). As can be seen in Figure 8, ABI meets these requirements with significant margin across the board.

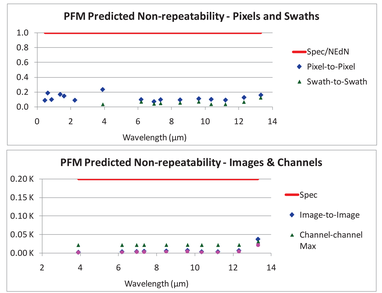


Figure 8. ABI Delivers Repeatable, High Quality Images

3.5 SNR and NEdT

The accuracy of weather products is driven by the signal-to-noise of the data from which they are produced. For reflective channels this is measured by the signal-to-noise ratio (SNR). For emissive channels the noise equivalent change in temperature (NEdT) is used. ABI's images score very well against this metric. As can be seen in Tables 2 and 3, there is significant margin against the SNR and most NEdT requirements, sometimes by more than a factor of 2. Even under worst case assumptions, the 3.9 µm channel meets the NEdT requirement.

Channel (µm)	Spec	CWE	%Margin
0.470	300	790	160%
0.640	300	360	20%
0.865	300	710	140%
1.378	300	840	180%
1.610	300	480	60%
2.250	300	780	160%

Table 2. High Quality VNIR Data Products Ensured by Excellent SNR

Channel	NEdT for 300K Scene			NEdT for 240K Scene		
(µm)	Spec	CWE	%Margin	Spec	CWE	%Margin
3.900	0.1	0.10	0%	1.40	1.27	10%
6.185	0.1	0.02	80%	0.40	0.06	90%
6.950	0.1	0.03	70%	0.37	0.09	80%
7.340	0.1	0.04	60%	0.32	0.11	70%
8.500	0.1	0.04	60%	0.27	0.09	70%
9.610	0.1	0.04	60%	0.22	0.08	60%
10.350	0.1	0.05	50%	0.21	0.08	60%
11.200	0.1	0.04	60%	0.19	0.07	60%
12.300	0.1	0.05	50%	0.18	0.08	60%
13.300	0.3	0.14	50%	0.48	0.22	50%

Table 3. High Quality MWIR & LWIR Data Products Ensured by Excellent NEdT

3.6 Dynamic Range

All ABI channels easily meet their dynamic range requirements. The most challenging (400K for the 3.9 µm channel) is predicted to be at least 410K.

3.7 Calibration Accuracy

The accuracy of many weather products depends heavily upon the absolute calibration of the input data. The ABI emissive channels easily meet their 1K requirement, as can be seen in Table 4. The reflective channels will be compliant with their absolute calibration requirement but ITT is still finalizing the exact margins.

ABI will deliver high quality images with significant margin against requirements

Channel	Spec	Prediction
3.9	1 K	0.7 K
6.185	1 K	0.5 K
6.95	1 K	0.5 K
7.34	1 K	0.5 K
8.5	1 K	0.5 K
9.61	1 K	0.5 K
10.35	1 K	0.5 K
11.2	1 K	0.5 K
12.3	1 K	0.5 K
13.3	1 K	0.5 K

Table 4. Emissive Channel Calibration Yields Accurate Images

4. Conclusion

The ABI PTM tests have shown that ABI will deliver high quality images with significant margin against requirements in many areas of interest to the users of its weather data. This ensures the highest quality weather products, predictions, and accurate tracking of severe weather such as hurricanes.