SEASONAL VARIATION IN THE MEASUREMENT OF GOES-16 ABI CHANNEL-TO-CHANNEL REGISTRATION

Bin Tan[1,2]*, Robert E. Wolfe*[1]*, Alan D. Reth*[1,3]*, John Dellomo*[1,4]

1. Goddard Space Flight Center, Greenbelt, MD
2. Science Systems and Applications, Inc., Lanham, MD
3. Chesapeake Aerospace, LLC, Annapolis, MD
4. Global Science & Technology, Inc., Greenbelt, MD

ABSTRACT

An Image Navigation and Registration (INR) Performance Assessment Tool Set (IPATS) was developed to assess the US Geostationary Operational Environmental Satellite R-series (GOES-R) Advanced Baseline Imager (ABI) and Geostationary Lighting Mapper (GLM) INR performance. Channel-to-channel registration (CCR) is one of the five INR performance metrics produced by IPATS. A seasonal variation is observed in the CCR assessment in north-south direction when one or both channels are reflective. However, indirect CCR, calculated as the difference of NAV measurements between two channels, does not present the similar seasonal variation. The phenomenon of the seasonal variation coincides with the annual change of the subsolar point location. The amplitude of the seasonal variation is related to the length and the direction of the shadow. Direct CCR, measured by IPATS directly, performs better than indirect CCR when both channels are visible wavelengths or emissive channels. For all other channel pair combinations, the assessment of indirect CCR is more accurate.

Index Terms**—** CCR, NAV, GOES-16, IPATS, Image Registration

1. INTRODUCTION

The first satellite of the US Geostationary Operational Environmental Satellite – R Series (GOES-R) was launched on November 19, 2016 and was designated GOES-16 upon reaching geostationary orbit ten days later. GOES-16 was relocated to its operational location of 75.2 degrees west and officially became GOES East on December 18, 2017. The Advanced Baseline Imager (ABI) is the primary instrument on the GOES-16 for imaging Earth's surface and atmosphere to significantly improve the detection and observation of severe environmental phenomena [1] [2].

An Image Navigation and Registration (INR) Performance Assessment Tool Set (IPATS), developed under the auspices of the NASA's GOES-R Flight Project, was designed and developed to support a broad range of ABI INR performance analyses [3]. It was built to measure five INR accuracy metrics: Navigation (NAV), Channel-to-Channel Registration (CCR), Frame-to-Frame Registration (FFR), Swath-to-Swath Registration (SSR), and Within-frame registration (WIFR).

CCR, also called band-to-band registration (BBR), is an important performance metric of the remotely sensed images. Accurate CCR is a fundamental assumption of the downstream algorithms which retrieve biogeophysical parameters or generate satellite data based products with multi-spectral channel data [4] [5]. The CCR assessment is a long-term task, usually starting from as early as the construction of the sensor and extending as late as the end of the sensor's mission. There are plenty of studies on the CCR accuracy of different satellite sensors and the methods to achieve high quality CCR assessment [6] [7] [8] [9]. The measurement of CCR does not have the issues present in registering multi-temporal images or multi-sensor images, like the change of the Earth's surface over time. However, CCR has its own known difficulties, such as the different spectral response at different wavelengths and the contrast reversal due to the differences in the reflective and emissive channels. These known problems have been well documented and studied [10] [11]. However, one undocumented impact factor on CCR measurements is revealed in monitoring the long-term GOES-16 CCR performance. In this paper, we will first introduce the data and the methodology used in this study. Then we present the long-term CCR record and discuss the source of CCR measurement errors, followed by a discussion of future work.

2. DATA AND METHODOLOGY

2.1 GOES-16 ABI Data

There are three types of ABI images: Full Disk (FD), which spans the entire viewable hemisphere, Continental United States (CONUS), which covers the United States, and

Mesoscale (MESO), which can be tasked to any local region [1]. The ABI data are gridded into the ABI fixed grid coordinate system, a two-dimensional angle space centered at the idealized location of a satellite in geosynchronous orbit [12]. GOES-16 ABI has 16 channels on three focal planes: Visible/Near-InfraRed (VNIR), Mid-Wave InfraRed (MWIR) and Long-Wave InfraRed (LWIR) (Table 1). VNIR channels are reflective, while MWIR and LWIR channels are emissive.

Table 1. GOES-16 ABI spectral channel characteristics.

Channel	Wavelength (µm)	Spatial Resolution		Focal Plane
		µrad	km at nadir	
1	0.45-0.49	28	1	VNIR (Reflective Channels)
2	0.59-0.69	14	0.5	
3	0.846-0.885	28	1	
4	1.371-1.386	28	1	
5	1.58-1.64	28	1	
6	2.225-2.275	56	2	
7	3.80-4.00	56	2	MWIR (Emissive Channels)
8	5.77-6.6	56	2	
9	6.75-7.15	56	2	
10	7.24-7.44	56	2	
11	8.3-8.7	56	2	
12	9.42-9.8	56	2	LWIR (Emissive Channels)
13	10.1-10.6	56	2	
14	10.8-11.6	56	2	
15	11.8-12.8	56	2	
16	13.0-13.6	56	2	

The FD image is a circle of angular diameter 17.4 degrees as measured from the satellite location with center at satellite nadir and circumference at the Earth limb. The FD data are produced every 10 to 15 minutes. In this study, we use the CCR and NAV assessment results, produced by IPATS, on FD data from December 18 2017 to November 4 2019.

2.2 Methodology

There are two ways, direct and indirect, to measure the CCR accuracy. The direct CCR is measured by correlating the images of two spectral channels directly to determine the location of peak correlation. CCR is defined as the difference between the correlation peak location and the nominal co-registration location. The CCR metric produced by IPATS is direct CCR [13].

Indirect CCR is calculated from the NAV assessment results as the difference between NAV errors of the images of two spectral channels. NAV is one INR performance metric produced by IPATS. The ABI NAV accuracy is assessed through comparing subsets of ABI images with subsets of Landsat 8 images, where Landsat 8 images are considered to have a negligible geolocation error.

In IPATS, the locations of ABI subsets for assessing ABI INR metrics, including NAV and CCR, are mostly along the shorelines of North and South America [13]. The shorelines are emphasized because they tend to exhibit high contrast, low spatial frequency image features that are particularly suitable for image registration at the spatial scale of ABI images.

3. RESULTS AND DISCUSSIONS

3.1 Long term CCR record

Figures 1 and 2 show the direct and indirect 24-hour CCR statistics respectively. These plots show channel 2 (a reflective VNIR channel) compared to channel 1 (another reflective VNIR channel), channel 7 (an emissive MWIR channel), and channel 13 (an emissive LWIR channel). A seasonal variation is observed in the north-south (NS) direction of direct CCR results comparing channel 2 to channel 7 and 13 (Fig. 1b and 1c).

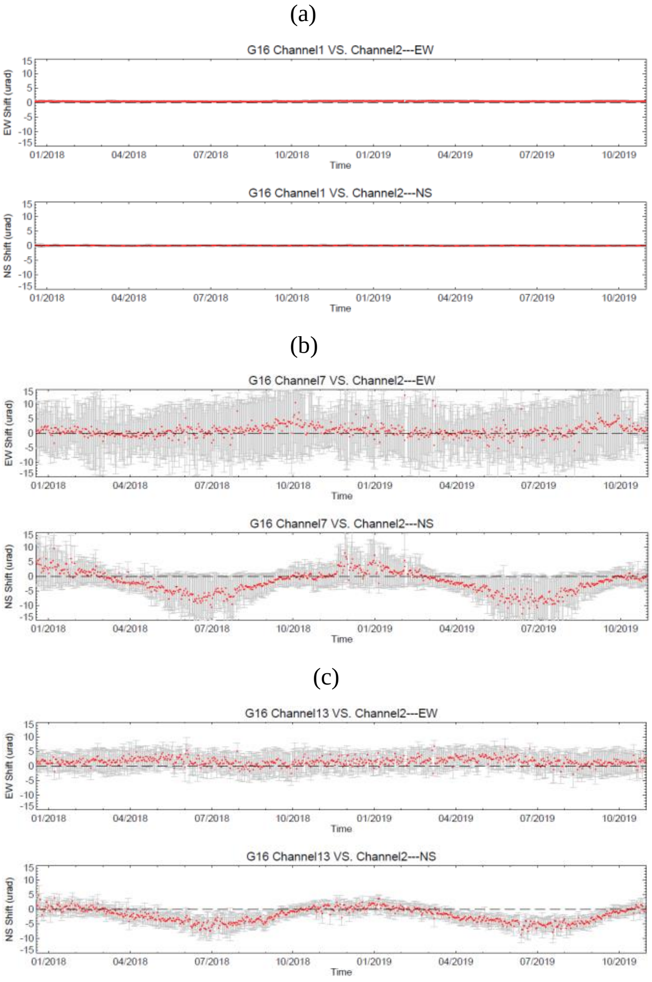

Figure 1. The time series plots of the 24-hour mean and standard deviation (STD) of the GOES-16 ABI direct CCR errors from December 18 2017 to November 5 2019.

The measured 24-hour mean NS errors oscillate from about -10 µrad to 5 µrad in the CCR of channel 7 versus channel 2 and from about -5 µrad to 1 µrad in the CCR of channel 13 versus channel 2. The NS errors reached southmost and northmost at the end of June and the end of December respectively. However, such a seasonal variation is not observed in the indirect CCR results (Fig. 2b and 2c). There is no seasonal variation observed in the east-west (EW) direction in either direct or indirect CCR long-term trends. The amplitude of the seasonal variation in CCR results between visible channels and NIR channels, or between two NIR channels, are much smaller at about 1-4 µrad (not shown here).

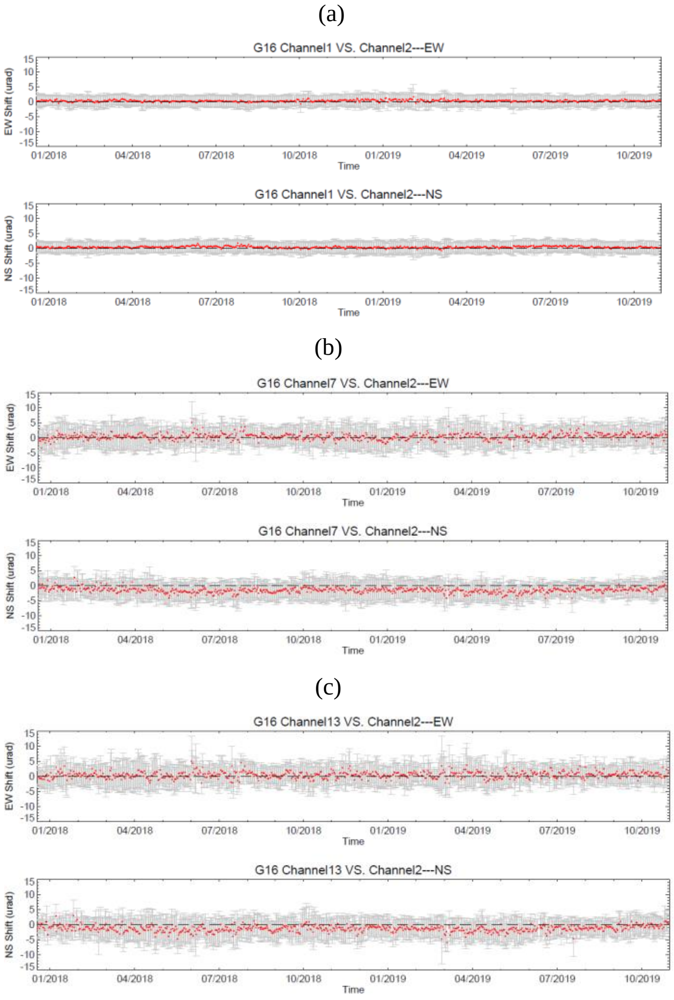

Figure 2. The time series plots of the 24-hour mean and STD of the GOES-16 ABI indirect CCR errors from December 18 2017 to November 5 2019.

The seasonal variation is not observed in CCR results when both channels are visible channels (Fig. 1a and 2a), or emissive channels (not shown here). When there is no seasonal variation, the 24-hour mean values of direct and indirect CCR are comparable but direct CCR has much smaller STD than indirect CCR. As shown in Fig. 1a and 2a, the STDs of direct and indirect CCR are about 0.5 µrad and about 2.5 µrad respectively. In the CCR between two emissive channels, the STD of indirect CCR is about 3-7 times of the STD of direct CCR. The smaller STD usually indicates the better quality measurements with smaller measurement errors.

3.2 Discussion and future work

The indirect CCR results show that the seasonal variation observed in direct CCR is not an intrinsic INR error of GOES-16 ABI, but a measurement error. This measurement error peaks at June and December solstice and is minimum at spring and fall equinox. This measurement error should be related to the sun because of two reasons. First, the temporal change of the error amplitude coincides with the subsolar point location change on the Earth. And second, the CCR measurements between emissive channels do not suffer this measurement error.

The impact of this measurement error on the reflective channels varies from channel to channel. This measurement error is observed in all CCR measurements when one or both channels are reflective, with the exception of both channels being in the visible spectrum (Fig. 1a). The amplitude of this measurement error varies for different channel pairs. Such a variation shows that the atmosphere condition, e.g. haze and cloud, is related to this measurement error. Because the opacity of haze and clouds is wavelength dependent, the dimensions of these phenomena are observed differently based on the spectral channel used. The shadows in the reflective channels due to the haze/cloud also varies in the images of different spectral channels.

From all of the above, the haze/clouds and their shadows are the source of this measurement error because of their unique characteristics: 1. the direction and the length of the shadow changes with the subsolar point location, and 2. the opacity of haze and clouds varies in different spectral channels.

In the future, we will compare the sensitivity of image registration algorithms to the haze/clouds/shadows, and apply the image registration algorithm with minimum sensitivity to the haze/clouds/shadows in generating the direct CCR results. Prior to such an algorithm, the direct CCR results should be replaced by the indirect CCR results when one or both channels are reflective except when both channels are the visible channels.

The improved CCR assessments will provide accurate data quality information and then benefit both data producers and data users. The accurate CCR assessments help the engineers of GOES satellites to improve the geolocation algorithms, operational parameters and future instrument design. The accurate CCR assessments also help the data users, who apply multi-spectral data of GOES-16 ABI in their research, to determine how to use the multi-spectral data optimally with the consideration of the CCR accuracy.

4. CONCLUSIONS

The CCR measurement accuracy is impacted by the haze/clouds and their shadows when one or both channels are reflective with the exception of both channels being visible. The measurement error changes seasonally and the amplitude of the seasonal variation is up to 15 µrad. The peaks are at June and December solstice and the error minima are at spring and fall equinox. The indirect CCR results should replace the direct CCR results for all channel comparisons that incur this measurement error.

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