

ATTEMPTS TO IMPROVE GOES IMAGE NAVIGATION

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Abstract

In this research we analyze the impact of various navigation parameter errors on image navigation accuracy. Methods that employ the Earth edge and image center are tested for GOES imagery. Navigation that is based on earth center determination from earth edge measurements does not rely on landmarks and hence is not vulnerable to excessive cloud cover. Navigation performance within one pixel has been realized at the Chinese National Satellite Meteorological Center for their spinning FY2B. An image center time series analysis indicates that, for the three axis stable GOES-9 during the Western Pacific observation mission, the image navigation accuracy is significantly reduced by errors in the forecast of spacecraft attitude. The biases in the roll and pitch can be nearly eliminated by introducing the attitude signal derived directly from earth center information. Results of these navigation improvements will be presented.

1 INTRODUCTION

Image navigation is an essential and fundamental component in data processing from geosynchronous meteorological satellites. Image navigation is based on S/C attitude, misalignment and orbit parameters[1], with image navigation parameters derived from landmarks, star sensing and ranging[2,3,4]. Navigation performance within one pixel has been realized at the Chinese National Satellite Meteorological Center for their spinning FY2B, which did not depend on any landmark matching, and only derived image navigation parameters from image center time series[5,6]. GOES I-M is the first series of 3-axis stabilized geosynchronous meteorological satellites to provide continuous viewing of the Earth. However, this makes image navigation parameter solutions and forecasting more complex. The S/C in-flight attitude bias, thermal distortions and earth sensors bias all decrease image navigation accuracy[7,8]. In this paper, we introduce a new GOES image navigation method based on the technique developed for Chinese FY2 satellite. It corrects image navigation parameters using image center (nadir) and image morphologic information[5,6], and does not depend on landmarks. Two experiments involving AMV validation of navigation improvements are shown. The first involves the correction of the S/C roll and pitch parameters automatically, and the second also attempts an interactive correction of the S/C yaw and RMA-PMA parameters.

2 ATTEMPTS TO IMPROVE GOES IMAGE NAVIGATION BASED ON IMAGE CENTER AND EARTH IMAGE SHAPE

2.1 GOES Image navigation and registration system description

The GOES I-M system has two working modes: one is "IMC ON", another is "IMC OFF". The GOES 10/12 operational satellites use "IMC ON" mode. The on-board IMC system remaps each image to a 'perfect GOES projection', so that every image received by the user is corrected for orbit, attitude, and spacecraft effects at the instrument during the scanning process [4]. For the "IMC OFF" mode, the image received by users represents the orbit, attitude and spacecraft effects on the imaging process. The GOES 9 mission was set to "IMC OFF" mode, so this paper uses GOES 9 data for image navigation tests.

GOES I-M image navigation parameters consist of three datasets as follow:

- S/C orbit: provides S/C positions.
- S/C Attitude: defined by roll, pitch, yaw parameters that change earth position in imager FOV

- Thermal change effect on instrument: defined by RMA-PMA parameters that change target shape in FOV

Fig.1 shows how the attitude and thermal change can effect image navigation. As fig1a indicates, the S/C attitude only leads to rotating and offset around the nadir. The thermal change effects on imaging process are more complex (Fig. 1b), as it will change the target shape in FOV, but in the nadir, thermal change effects do not change the imaging process. So it's possible to derive thermal change RMA-PMA information by earth image shape analysis.

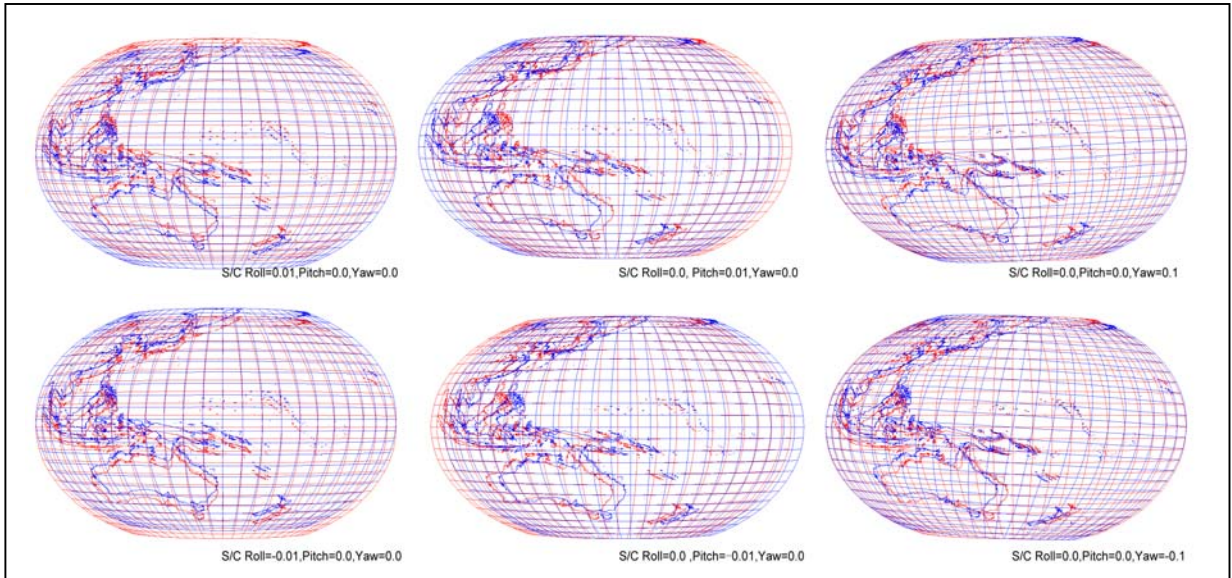


Figure 1a: S/C Attitude effect on image navigation

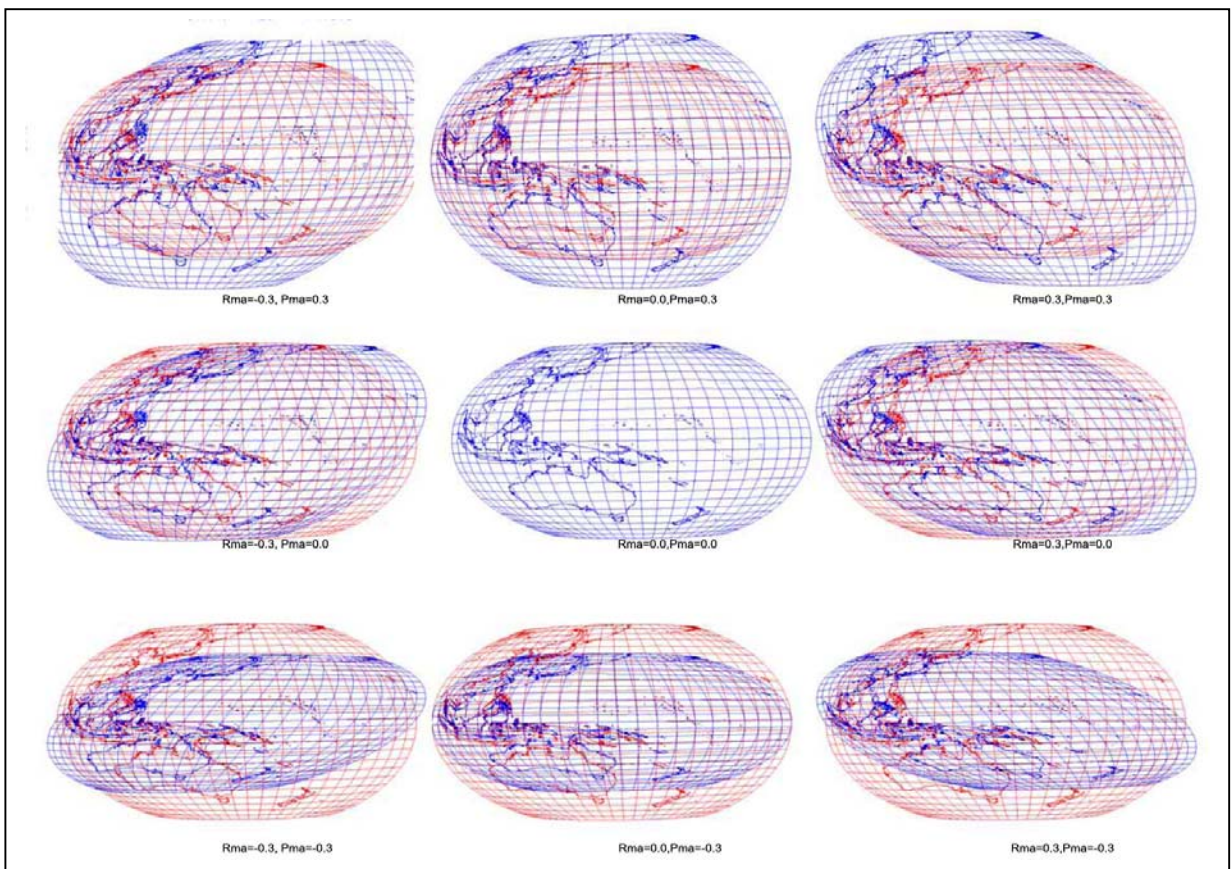


Figure 1b: Thermal change effect on image navigation

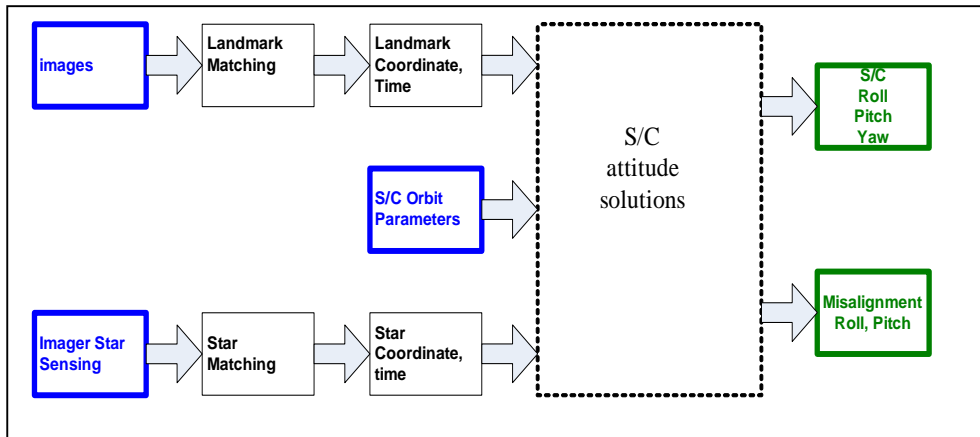


Figure 2: Normal Image Navigation Parameter Decision Flowchart

Fig 2 shows how normal image navigation parameter works. GOES needs star looks, range measurements and landmark measurements to derive image navigation parameters[9]. The problem is clouds often obscure landmarks, so it can be difficult to get enough landmarks in monsoon season. The current GOES operational image navigation provides difference accuracies in day time and at night, for landmark matching uses Visible channel (1km in nadir) in the daytime and IR channel (5km in the nadir) at night.

The GOES spacecraft attitude is maintained and controlled with respect to the earth by means of an infrared earth sensor (ES), which provides the reference, and a momentum bias system with two skewed momentum wheels (MWs) for pitch and roll control [2]. Fig 3. shows a three day GOES9 S/C attitude time series. According to this figure, S/C attitude can become discontinuous while the attitude dataset is renewed. This will result in a image navigation bias.

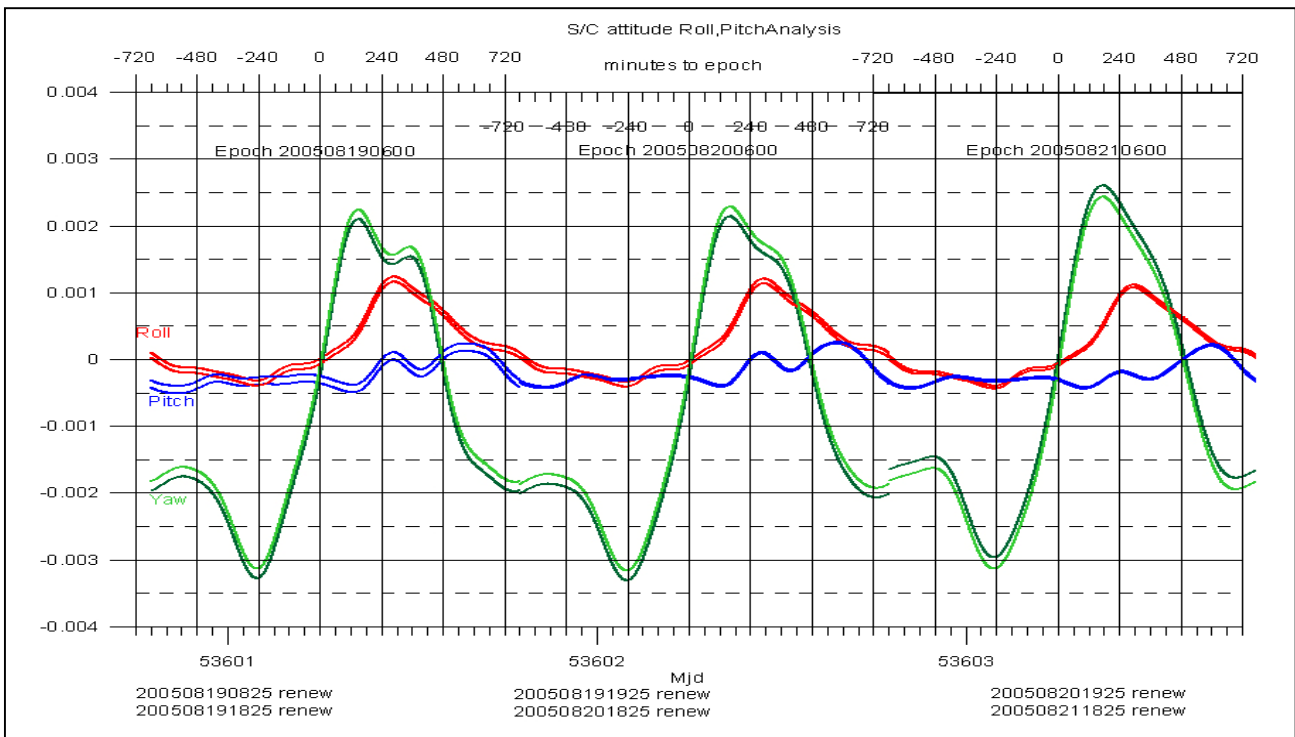


Figure 3: GOES 9 S/C attitude time series

2.2 Improved Image Navigation Parameter Decision

The image navigation process includes a lot of coordinate transform, finished by a Attitude Transform Matrix. The small Euler angle model is as follows:

$$R_x(ROLL) \bullet R_y(PITCH) \bullet R_z(YAW)$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(ROLL) & \sin(ROLL) \\ 0 & -\sin(ROLL) & \cos(ROLL) \end{bmatrix} \bullet \begin{bmatrix} \cos(PITCH) & 0 & -\sin(PITCH) \\ 0 & 1 & 0 \\ \sin(PITCH) & 0 & \cos(PITCH) \end{bmatrix} \bullet \begin{bmatrix} \cos(YAW) & \sin(YAW) & 0 \\ -\sin(YAW) & \cos(YAW) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos(PITCH) & 0 & -\sin(PITCH) \\ \sin(ROLL)\sin(PITCH) & \cos(ROLL) & \sin(ROLL)\cos(PITCH) \\ \cos(ROLL)\sin(PITCH) & -\sin(ROLL) & \cos(ROLL)\cos(PITCH) \end{bmatrix} \bullet \begin{bmatrix} \cos(YAW) & \sin(YAW) & 0 \\ -\sin(YAW) & \cos(YAW) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos(PITCH)\cos(YAW) & \cos(PITCH)\sin(YAW) & -\sin(PITCH) \\ \sin(ROLL)\sin(PITCH)\cos(YAW) - \cos(ROLL)\sin(YAW) & \sin(ROLL)\sin(PITCH)\sin(YAW) + \cos(ROLL)\cos(YAW) & \sin(ROLL)\cos(PITCH) \\ \cos(ROLL)\sin(PITCH)\cos(YAW) + \sin(ROLL)\sin(YAW) & \cos(ROLL)\sin(PITCH)\sin(YAW) - \sin(ROLL)\cos(YAW) & \cos(ROLL)\cos(PITCH) \end{bmatrix}$$

Current operational GOES-I-M image navigation uses the following Attitude Transform Matrix; a simpler form of the small Euler angle model mentioned above

$$\begin{bmatrix} 1 - 0.5 * (YAW^2 + PITCH^2) & -YAW & PITCH \\ YAW + ROLL * PITCH & 1 - 0.5(ROLL^2 + YAW^2) & -ROLL \\ -PITCH + ROLL * YAW & ROLL + PITCH * YAW & 1 - 0.5(ROLL^2 + PITCH^2) \end{bmatrix}$$

If S/C attitude ROLL, PITCH and YAW is small enough, we can do a further simplification as follows:

$$\sin(ROLL) \cong ROLL; \sin(PITCH) \cong PITCH; \sin(YAW) \cong YAW;$$

$$\cos(ROLL) \cong 1; \cos(PITCH) \cong 1; \cos(YAW) \cong 1;$$

$$\sin(ROLL)\sin(PITCH) = 0;$$

$$\sin(ROLL)\sin(YAW) = 0;$$

$$\sin(PITCH)\sin(YAW) = 0$$

$$R_x(ROLL) \bullet R_y(PITCH) \bullet R_z(YAW) \cong \begin{bmatrix} 1 & YAW & PITCH \\ -YAW & 1 & ROLL \\ -PITCH & -ROLL & 1 \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \begin{bmatrix} 1 & YAW & PITCH \\ -YAW & 1 & ROLL \\ -PITCH & -ROLL & 1 \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

In the Nadir, we can get:

$$\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \begin{bmatrix} 1 & YAW & PITCH \\ -YAW & 1 & ROLL \\ -PITCH & -ROLL & 1 \end{bmatrix} = \begin{bmatrix} PITCH \\ ROLL \\ 1 \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

X' and y' could be derived from Nadir image coordinate offset. The simplified Attitude Transform Matrix becomes a linear function now. Then ROLL and PITCH parameters are very easy to get solutions. Fig4 gives the bias analysis of simplified attitude transform matrix.

GOES 9 S/C yaw dynamic range: -0.003~0.003 radius

S/C Roll, Pitch dynamic range: -0.0005~0.0015 radius

Roll, Pitch solution bias to Navigation <<0.2pixel(IR Channel), so for GOES I-M image navigation mission, it's accuracy is enough.

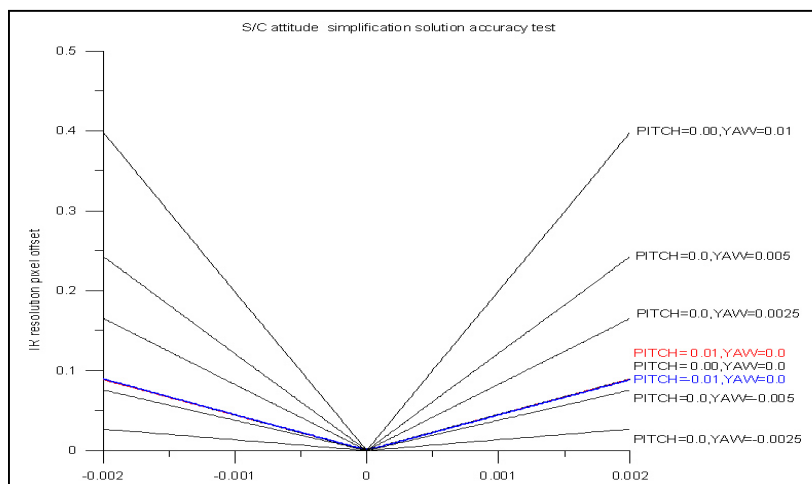


Figure 4: Bias analysis for simplified attitude transform matrix

2.3 High Accuracy and Stable Earth Nadir Searching

In order to derive S/C ROLL and PITCH parameters, a high accuracy and stable S/C nadir searching algorithm has been developed. Both moon incursion and polar region high cloud effects on earth edge detection are eliminated by a self-adaptive filter and iteration. As shown in Fig. 5, the green line is the GOES9 nadir image coordinate forecast, the red line is the Nadir searching result, and the lower part in fig. 5 is the GOES nadir position forecasting error. Sometimes the nadir image coordinate forecasting errors are more than 4 pixels. That's a big bias for quantificational application like AMV. The nadir positions have highly repeatable diurnal changes (shown in Fig.5), so the nadir image coordinate forecasting errors are mainly from the image navigation parameter solutions, not from the S/C control itself. The most significant navigation bias for GOES9 appears to come from the S/C attitude parameters. Fig.2 also supports this assumption.

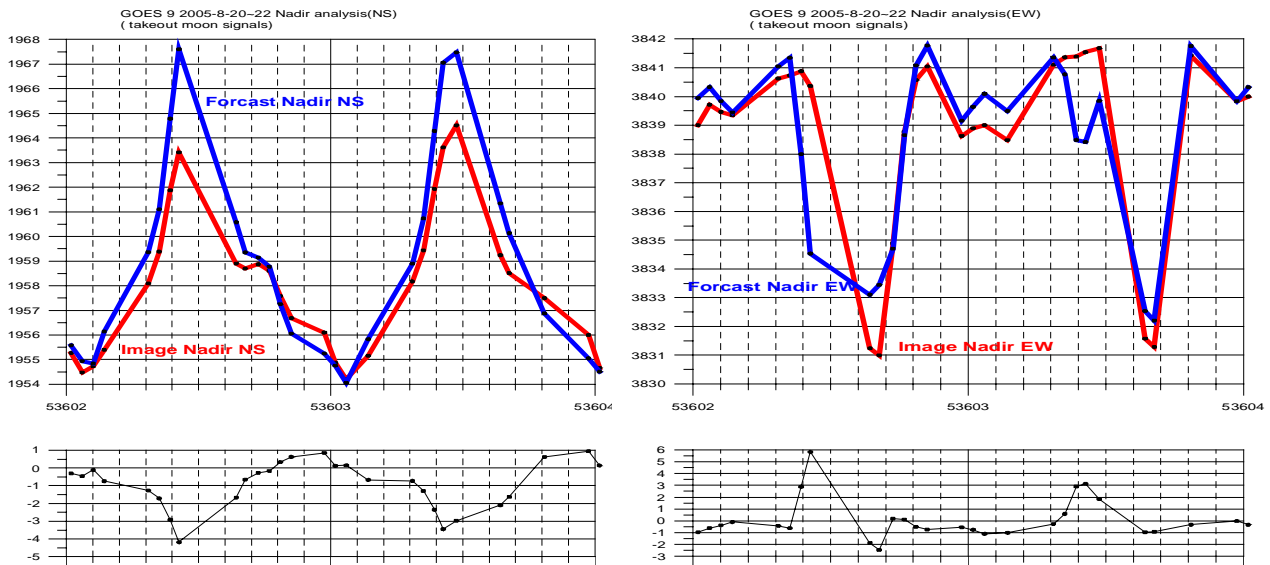


Figure 5: GOES9 nadir image coordinate analysis

3 CASE STUDY & VALIDATION

3.1 Data

19 full disk GOES9 images from 08/20/2005 to 08/21/2005 are considered in this case study. The data are stored in Mcidas Local file format, Each dataset includes 5 channel images and image navigation parameters from the GVAR data stream. Only channel-4 (10.2 - 11.2 μm) is used for earth edge detection, image nadir recognition and earth image morphologic analysis. According to this information, the image navigation parameters are derived and the dataset navigation is renewed.

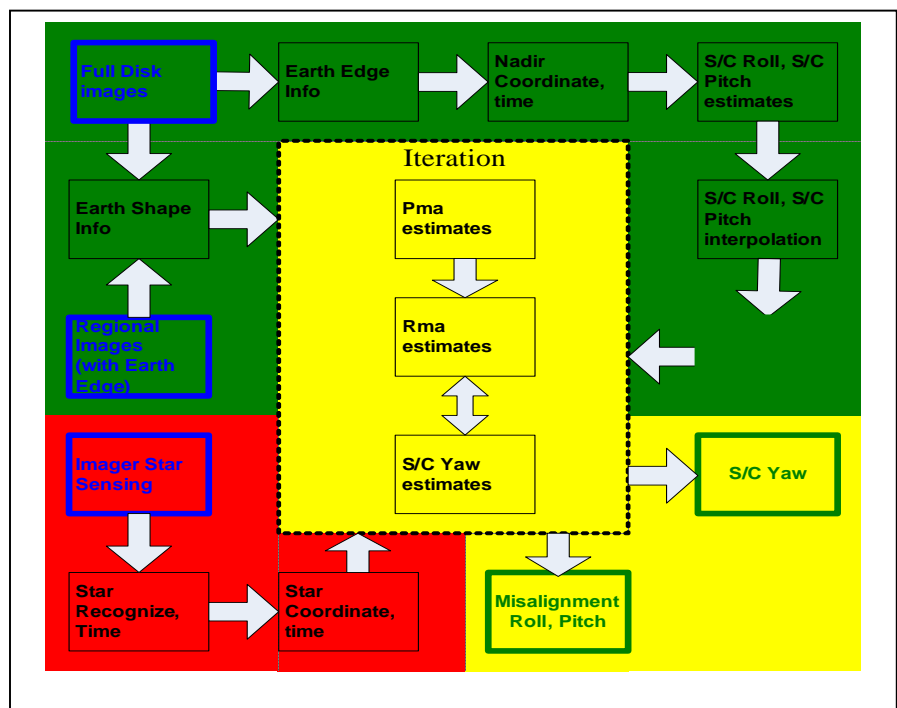


Figure 6: Improved Image Navigation Parameter Decision Flowchart

3.2 Methodology

An R&D system was developed to verify the new image navigation method. Fig.6 shows how it works. According to the simulation and bias analysis, different navigation parameters have different effects on image navigation. The most important part in S/C attitude, so the green zone in the flowchart has been finished and corrects S/C roll and pitch parameter automatically. The red zone in the flowchart needs imager star sensing information we can't access at present. So we do an interactive operation to correct S/C Yaw and RMA-PMA; this part in the flowchart is marked in yellow. In this case study, two test are considered. The first one just automatically corrects S/C roll and pitch parameters. The second one interactively corrects yaw parameters and attempts to correct RMA-PMA parameters based on first correction. Both tests renew the image navigation parameters and write it back to dataset files. These corrected files were then employed by the CIMSS AMV retrieval system to derive AMVs and make validations.

3.3 Results

Fig. 7 shows the test results, from left to right, they are: the uncorrected images, Automatic S/C ROLL and PITCH corrections, and then added interactive S/C YAW parameter correction result. Fig. 8 gives a 24-hour period of image navigation test result. During the interactive image navigation test, only S/C yaw parameter was corrected by manual operations. The RMA parameter was set to be zero and the PMA parameter was the same as parameters from the GOES 9 GVAR data. Scale analysis and simulations show the PMA parameter forecasting bias did not effect image navigation very much, and the RMA effect could be absorbed by YAW correction while RMA is very small. The S/C ROLL and PITCH correction give very reasonable results. Some abnormal info in the GOES attitude forecasting are corrected (shown in Fig.8 with red and blue arrows), but the S/C yaw parameter interactive correction result is not quite smooth. Perhaps it belongs to the bias from the interactive operation and the signal from RMA. The S/C yaw parameter correction could be improved by using imager star sensing to help separate the RMA signal from the yaw parameter.

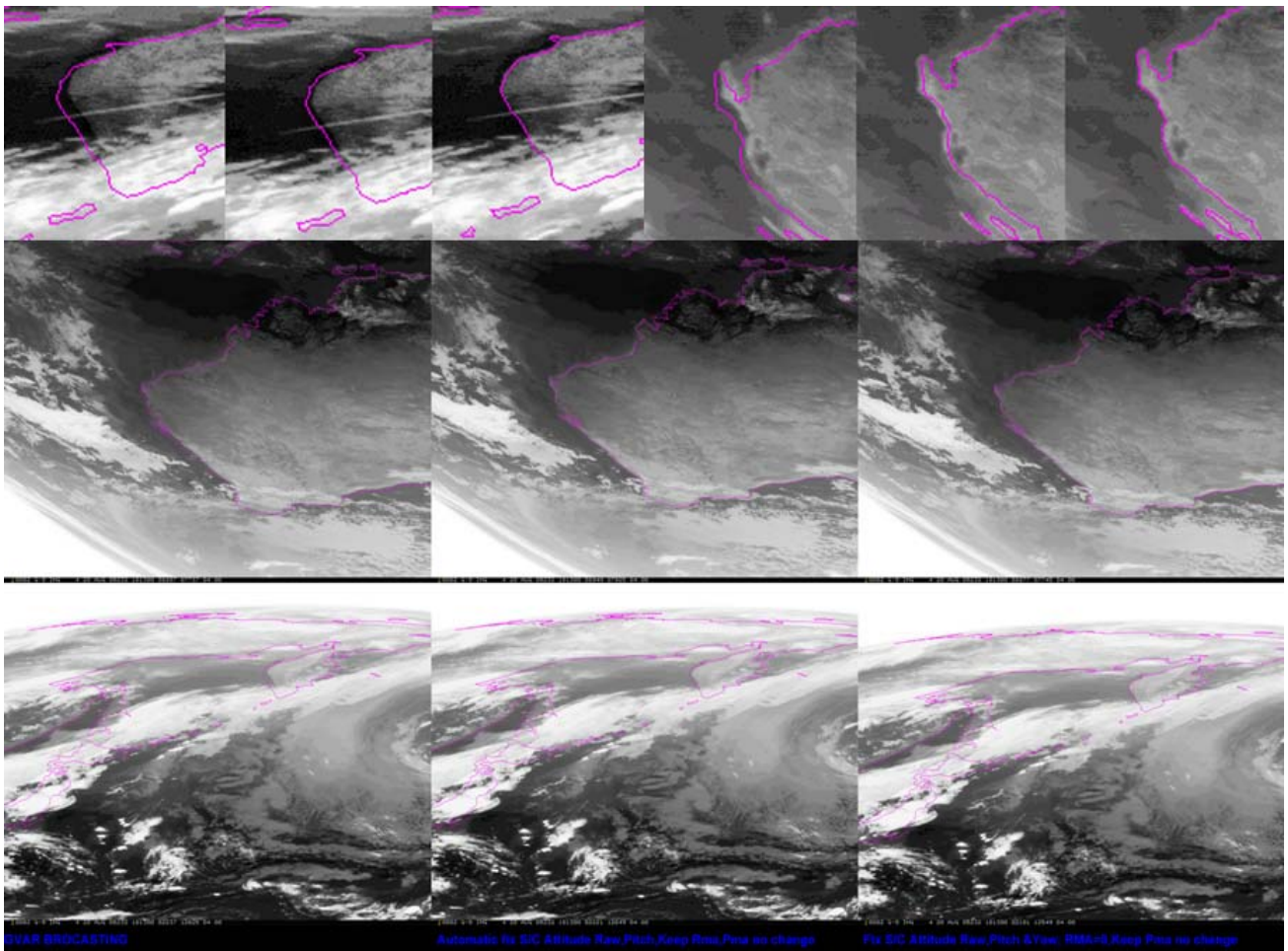


Figure 7: 20050820 1013UTC image navigation test

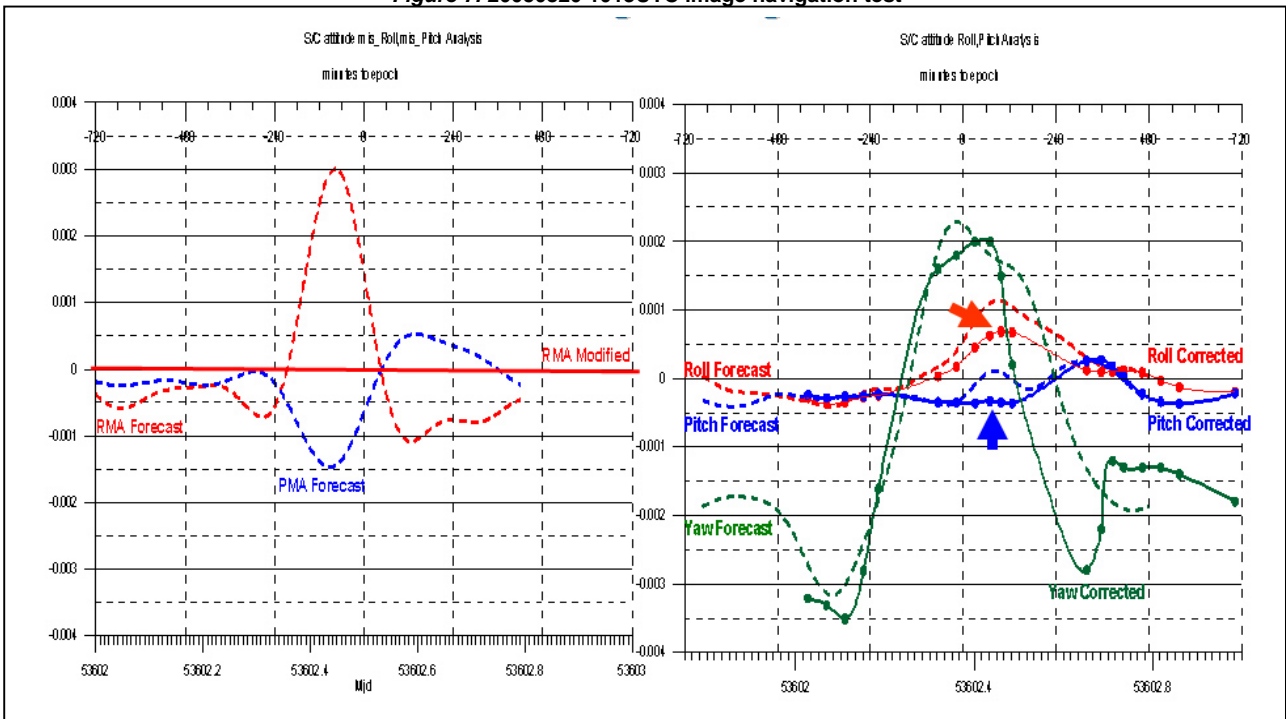


Figure8: 20050820 image navigation test

3.4 AMV Validation

Both the interactive and automatic image navigation results renew the image navigation parameters, which are written back into the test dataset in Mcidas Local file format. We then use the SSEC/CIMSS AMV program to derive AMVs and assess the effects of the navigation corrections. The result for AMV coverage effects is shown in Fig.9, and the homogeneous comparison of AMVs with Raobs is presented in Table1. The AMV from just the automatic correction of S/C roll and pitch parameters show small improvements compared to the current SSEC/CIMSS landmark navigation based AMV. The new method does not ever depend on landmarks, so perhaps we can use FULL DISK images to derive S/C attitude and using interpolation to provide more accurate attitude information for regional scans.

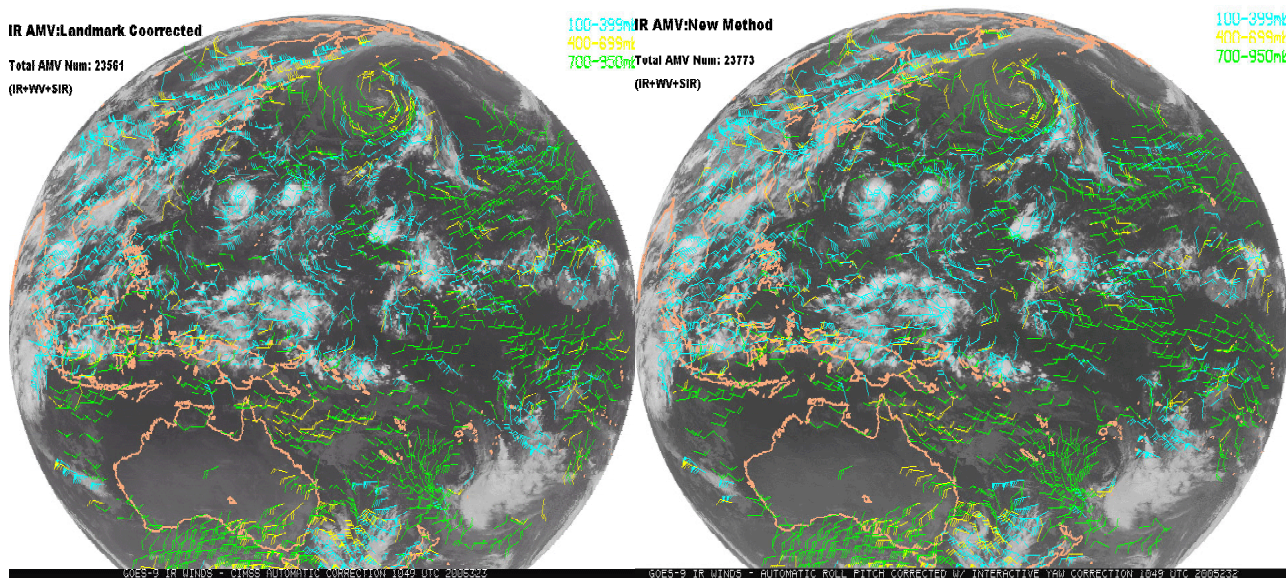


Figure 9: 20050820 1049UTC AMV validation

AMV Tracing Method	CIMSS Landmark Navigated		S/C Roll, Pitch Auto corrected		S/C Roll, S/C Roll, Pitch corrected. S/C Yaw , PMA and RMA interactive corrected	
	RAW	AQC	RAW	AQC	RAW	AQC
Matching Distance	100Km	100Km	100Km	100Km	100Km	100Km
Homogeneous Comparisons						
Samples	246	113	246	113	246	113
Speed Bias	0.51	2.15	-0.03	1.59	-0.08	1.27
VRMS	8.73	6.29	8.64	5.70	8.53	5.51
Average Vector Relocation Distance (Km)						
Match with Uncorrected Images	3.21	5.45	26.64	26.34	27.16	26.62

Table.1: Image Navigation Validation via AMV

4 SUMMARY

Most of the image navigation bias and variance for GOES9 comes from S/C attitude Roll and Pitch parameters. A new Automatic Image Navigation test demonstrates the possibility to automatic correct S/C attitude Roll and Pitch parameters, and the case studies presented show the image navigation accuracy significantly improved. A further test with Interactive Image Navigation demonstrates the possibility to correct the S/C Yaw parameter and misalignment parameters. GOES9 S/C yaw parameter correction has slight improvements on image navigation.

AMV validation shows, even by just using the corrections for S/C attitude ROLL, PITCH parameters, there are 18.76% more AMVs traced and pass qualify control compared to no navigation corrections. Also, 1% more AMVs are traced compared with SSEC/CIMSS current landmark navigation code. The strong advantage of the new method is that it can be applied without the need for landmarks, and can be used for attitude forecasts and applied to regional scan like SRSO or RSO (local area rapid scans operations). Combined with imager star sensing data, it is possible to build up an automatic image navigation system, and the Interactive Image Navigation test demonstrated this possibility.

This new navigation technique can be applied to the GOES "IMC ON" mode, which is important since this will be the normal operational mode (GOES-E/W). The technique will need slight modifications to create a pixel-level look up table. Operational GOES AMVs may improve by using this look up table since it should improve frame to frame co-registration.

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