Sub-satellite Point Observation and Image Registration Accomplishment with GOES-9 IMC-Off Status

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Abstract: GOES-9 has been operated with the status of the Image Motion Compensation(IMC) off since last October. As the IMC function turned off, the sub-satellite point(SSP) of GVAR data was changed with the effect of the satellite motions. This makes the image registration, to maintain pixels within an image and between successive images to their earth-referenced information, not to be possible any more. In the paper, we introduce the method to accomplish image registration and the result of the SSP observation with the status of IMC off.

Keywords: GOES, GVAR, Image Registration, Sub-satellite Point.

1. Introduction

GOES-9 has become the operational meteorological satellite over the Western Pacific and Eastern Asia, positioned at 155 degrees East, by replacing the Japan Meteorological Agency's GMS-5 since 22 May 2003. Korea Aerospace Research Institute(KARI) is providing GOES-9 images with real-time Internet service using Meteorological Sensor Ingest System(MESIS) developed for GOES-9 data ingest and processing in house. Currently GOES-9 is being operated with the status of the Image Motion Compensation(IMC) off.

As the IMC function became off, the SSP of GOES-9 image data has not been fixed to the correct image at 155 degrees East any more. Hence, we can observe the SSP movement easily with watching successive GOES-9 images by the MESIS' moving window display menu. Those SSP change means that pixels within an image are not fixed in successive images, that is, the image registration of GOES Image Navigation and Registration(INR) System is not performed any more.

In this paper, we study a noble method to accomplish image registration under the status of IMC-off by fixing the SSP of GOES-9 image at 155 degrees of east longitude. For this, first of all, we present the observation result of SSP change in GOES-9 image during IMC-off period (1 October 2003 ~ 31 May 2004) and look around SSP change trend with the status of IMC off. Also we investigate the pixels location change corresponding to the SSP change. This was possible by calculating the distance between pixels which have same earth-referenced information of IMC-on image and IMC-off image. Lastly we introduce the method to accomplish image registration on IMC-off images.

The SSP of GOES-9 image was extracted from the GVAR ancillary data using ELUG(Earth Location User Guide) disseminated by NOAA(National Oceanic and Atmospheric Administration).

We regard the IMC-on image as the reference image in this paper. Even under the status of IMC on, GOES INR performance shows the marginal performance(4km at Noon ± 8h) with respect to the specification. But we can expect much bigger error in IMC-off image case comparing with IMC-on image. Moreover our concern is concentrated on transforming IMC-off image into "IMC-on image"-like, not the exact geometric residue calculation. Therefore, all coastline overlapped with GOES-9 image are set with the status of IMC on. Though GOES-9 imager is capable of positioning the scan mirror in any direction, we ignore the attitude and the angle of the imager.

2. Image Motion Compensation(IMC)

1) Satellite's orbital motion

Ideally if the satellite located on the geosynchronous orbit, it would revolve around the Earth in a perfectly circular orbit. Also, the SSP of observed images would be fixed at one point. But this is only possible by the assumption that there is no power and energy interference over the orbit and attitude of satellite.

In real world, the satellite's orbit is slightly elliptical and inclined with respect to the equator affected by the gravity of Sun and stars and Earth's asymmetric gravity field, Sun's radiation pressure and so on. Therefore, it is oscillating up and down with respect to the equator like figure eight pattern to a person on ground[1]. The SSP of image is also changed corresponding with above referred satellite's motion.

2) Role of IMC

The key characteristic of GOES INR system is the onboard processing by correcting an imager's pointing to null effects of the orbit and the attitude perturbation by using IMC coefficients uploaded from the ground system. IMC coefficients describe the orbit and attitude perturbation that can be predicted on the next day.

Under the status of IMC on, the SSP which the satellite points on the surface of the Earth directly is fixed regardless of time. Therefore the location of pixels of observed image is being entailed between successive

images to their earth-referenced latitude and longitude like one of an image observed on the ideal geostationary orbit.

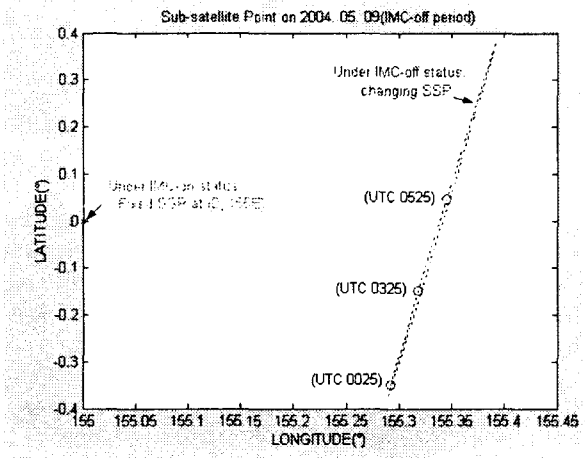

Fig. 1. SSP change of IMC_on and IMC_off image during a day.

3. SSP Observation Result

We observed SSP change in GOES-9 images during IMC-off period (1 October 2003 ~ 31 May 2004) to look around SSP change trend with the status of IMC off.

1) IMC function evidence

First the SSP observation result during a day of IMC-on and IMC-off image is shown in Fig. 1. This figure evidently depicts the function of IMC referred earlier. We can find that the SSP of IMC-on image is fixed at one point, (0, 155E).

The SSP of IMC-off image is changed to almost like the figure eight pattern. This indicates that the satellite motion is being reflected in the observed image. As a result of observation, we can observe that the SSP changes during a day is (0°~0.15°) in E-W and (0.25°~0.9°) in N-S direction with the status of IMC off.

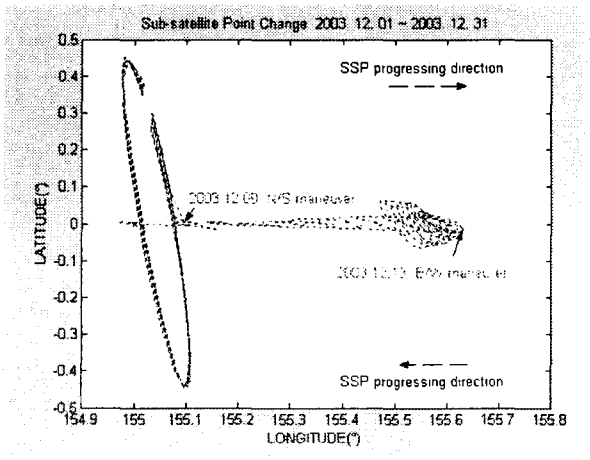

Fig. 2. SSP change observation result during December 2003.

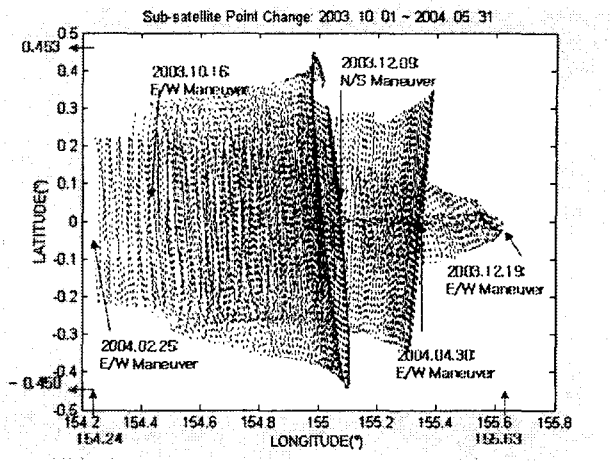

Fig. 3. The maximum permissible limit of GOES-9 SSP changes.

2) Relationship with Station Keeping Maneuvering

The SSP values used for this observation were calculated from the GVAR ancillary data. Thus it is difficult to assert that these values are exactly same to real values the satellite points on the surface of the Earth. In addition, though the instrument's SSP is changing with the scanning direction, only one SSP point is so extracted that observed result might have a little error in accuracy.

Nevertheless the point of time when the magnitude or direction of the SSP trace is suddenly changed is exactly same with the time when the GOES-9 station keeping maneuvering was executed in Fig. 2. This fact tells us that observed results have the high reliability and are closely related with the satellite's real attitude and orbit.

The observation result of whole period is shown in Fig 3. This shows that the maximum permissible limit with the status of IMC off is (-0.45° ~ 0.453°) in latitude and (154.24° ~ 155.63°) in longitude. Namely the SSP with the IMC off seems to permit the around 1° in latitude and 1.4° change in longitude.

Additionally, when the SSP may get out of the limit, the station keeping maneuvering was executed to remain SSP within the permissible limit, the yellow box of Fig. 3. We also find the E/W Maneuvering execution period of GOES-9 is about 2 months and N/S Maneuvering is more than 8 months.

4. Pixel shift between IMC-on image and IMC-off image

We can observe the IMC-off image in Fig. 4 and 5 are not consistent with the shoreline which is based on the IMC-on image. The shoreline database is World Data Bank-II provided by Interactive Data Language(IDL).

Fig. 4 and 5 show the vicinal region of Korea Peninsular extracted from a GOES-9 full disk image in the visible channel. GOES-9 images of Fig. 4 and 5 are shown to move in West direction and in North direction relatively comparing to the shoreline.

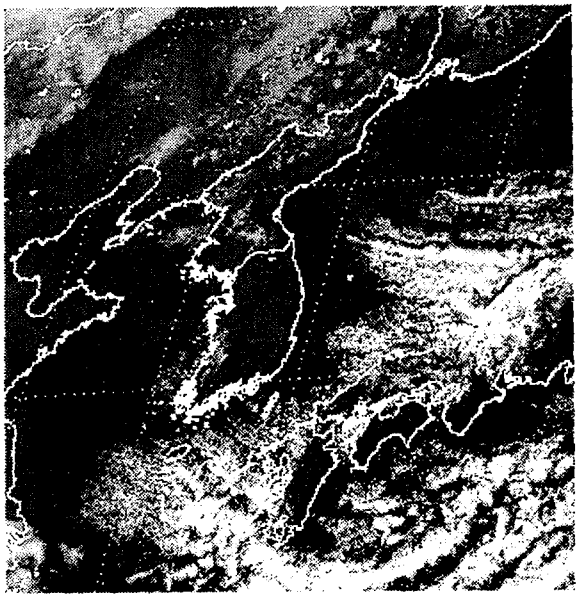

Fig. 4. IMC-off image(1) before image registration (2003/12/22 03:25:00(UTC)).

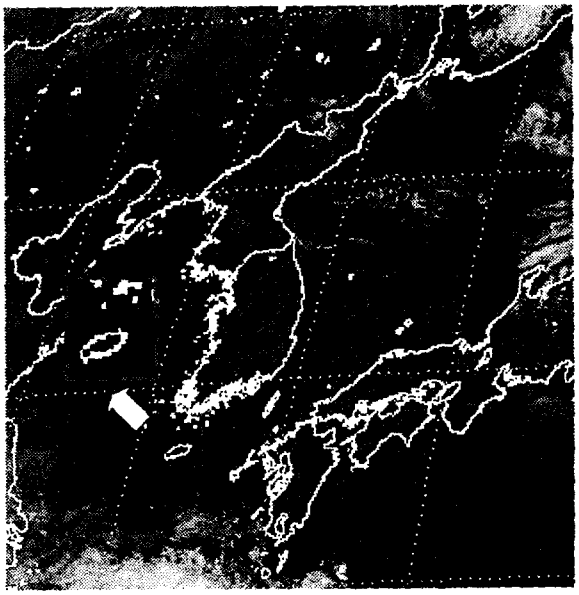

Fig. 5. IMC-off image(2) before image registration (2004/04/17 00:25:00(UTC)).

Based on SSP values of Table 1, we can estimate that these movements are resulted from the SSP change. Because the SSP of Fig. 4 are slanting to the east direction and the SSP of Fig. 5 are to the south direction.

To investigate the relative pixel shift between IMC-on and IMC-off images, we calculate the difference of pixels' location (line, pixel) which have same earth-referenced (latitude, longitude). For this we used navigation data, which shows the location of the pixels within an image and their earth-referenced coordinate, extracted from GVAR ancillary data using ELUG program. The test area was restricted within latitude (20°~50°) and longitude (110°~150°). In next equations, (L_on, P_on) is location of pixels within IMC-on image indicating same (latitude, longitude) with (L_off, P_off) of IMC_off image.

$$\text{Diff\_line} = |(L_{on} - L_{off})| \quad (1)$$

$$\text{Diff\_pixel} = |(P_{on} - P_{off})| \quad (2)$$

$$\text{Pixel shift} = \sqrt{Diff\_line^2 + Diff\_pixel^2} \quad (3)$$

Using above equations, the 'Jeju Island' in magnified box of Fig. 5 is found to be 31.75 km apart from that of IMC-on image. The pixel shift of Fig. 4 and 5 are calculated as shown in Table 1. With this result, we can find that the pixel shift direction and distance are related to the SSP change. With the effect of Earth curvature, the pixel shift became bigger as the calculated pixel is closer with related SSP.

Table 1. Pixel shift calculation result of IMC-off images.

Image	Fig. 4.	Fig. 5.
SSP(Lat, Lon)	(-0.015°, 155.61°)	(-0.32°, 155.24°)
Diff_line	16 ~ 20 km	13 ~ 32 km
Diff_pixel	12 ~ 54 km	3 ~ 33 km
Pixel shift	16 ~ 58 km	26 ~ 36 km

5. Image Registration for IMC-off images

In this section, we propose the image registration accomplishment procedure for IMC-off images.

1) Generating Earth image projected from IMC-on SSP

First, we generated an earth image projected from (0, 155). Please refer to the CGMS document [3] about detailed procedures of generating projection earth image. As our interest area is the vicinal region of Korea Peninsular, the related area is extracted within latitude (20°~50°) and longitude(110°~150°).

2) Image Navigation of GOES-9 image

In the previous procedure, location of pixels (line, pixel) within the projected image and their earth-referenced information (latitude, longitude) were acquired. With accomplishing the image navigation about pixels within a GOES-9 image using ELUG program, we can acquire location of pixels (line, pixel) within a GOES-9 image and their corresponding (latitude, longitude) values. A GOES-9 image is also extracted as much as the test area of previous procedure.

3) Insert pixels of GOES-9 image into the projected image

Pixels within a GOES-9 image which corresponds the earth-referenced coordinate within the earth projected image is extracted from the location indicated by image navigation result and inserted into the projected image like Fig. 6.

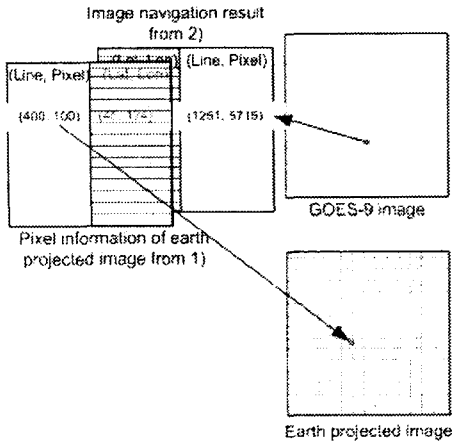

Fig. 6. Insert pixels of GOES-9 image into the projected image.

4) Shoreline Overlay

To express the earth surface over the projected image inserting by pixels of GOES-9 image data, we overlay the shoreline using IDL and then get the result image shown as Fig. 7 and 8. These figures show that IMC-off images after accomplishing image registration are exactly consistent with the shoreline based on the IMC-on image. This means pixels of IMC-off images are corresponding to the same earth-referenced information with no relationship of SSP changes.

6. Conclusion

If we watch the successively observed IMC-off images, we can find they are moving significantly in north and south and also moving slightly east and west direction. This is the reason of that image registration is not available anymore as IMC function became off. This motivated us to consider how to accomplish image registration having no concern with IMC function. With the image registration accomplishment using earth image projected and ELUG program, we can transform IMC-off images to be like IMC-on images.

This is a good example to show the necessity of developing ground-based INR system against the unforeseen on-board trouble, even if the primary INR system is based on on-orbit processing.

References

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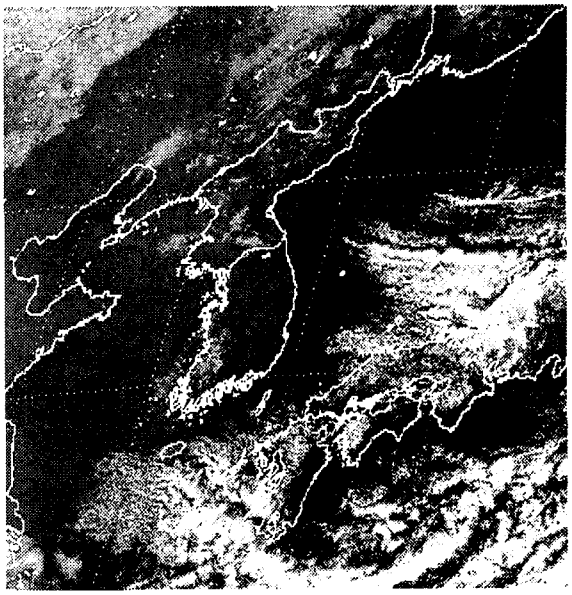

Fig. 7. IMC-off image(1) after image registration (2003/12/22 03:25:00(UTC)).

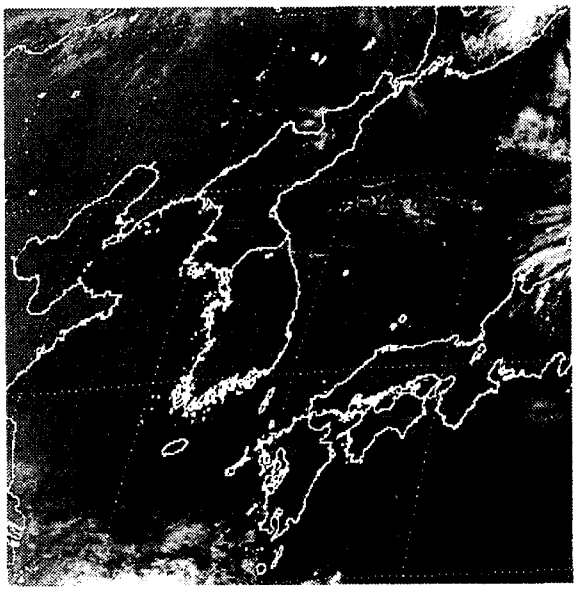

Fig. 8. IMC-off image(2) after image registration (2004/04/17 00:25:00(UTC)).