Study on Over-sampling for Imager

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Abstract

This report describes the potential improvement of the effective ground resolution of MTSAT (Multi-functional Transport Satellite) Imager.

The IFOV (Instantaneous Field of View) of MTSAT Imager is 4 km for infrared and 1 km visible. A combination of some images acquired by the MTSAT Imager could generate 2 km-latticed infrared images. Furthermore, it is possible to generate an effective 2 km IFOV image by the enhancement of the 2 km-latticed image using Digital Signal Processing. This report also mentions the on-orbit demonstration of this concept.

1. Introduction

The purpose of this study is to demonstrate the effect of 2 km infrared imagery from on-orbit spacecraft. And the study is made on the premise that the existing instrument and ground system should be put to use to minimize the cost and risk of improvement. The design modification of the MTSAT Imager and ground image processing system for this study is not required.

This report describes the MTSAT spacecraft and Imager design, a method of image combination, a technique of image enhancement, and an approach to on-orbit demonstration.

2. MTSAT and Imager

The MTSAT spacecraft configuration, shown in Figure 1, is a three-axis, body-stabilized design capable of continuously pointing the optical line of sight of the Imager to the earth. The use of a single-wing solar array configuration allows the passive north-facing radiation cooling of the Imager. A solar sail and trim tab provide the fine balance control of the solar radiation pressure.

The Imager consists of Sensor Module, Power Supply Module, and Electronics Module. The Sensor Module contains the telescope, scan assembly, detector, thermal louver, and passive radiant cooler. Figure 2 shows a schematic appearance of the Sensor Module.

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The Imager contains a servo-driven, two-axis gimballed scan mirror. The position and size of a scan area are controlled by command from the ground system, and so the Imager is capable of various image sizes. The scan start position of a scan area is specified by 8 micro-radians (0.28 km) in the north/south direction and 16 micro-radians (0.57 km) the east/west.

Ground sampling distance, shown in Figure 3, is 112 micro-radians (4 km) in the north/south direction and 64 micro-radians (2.3 km) the east/west for infrared imagery.

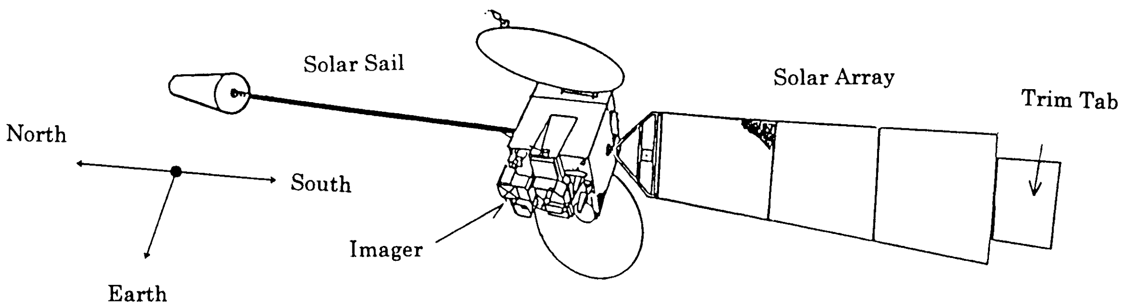


Figure 1 MTSAT On-orbit Configuration

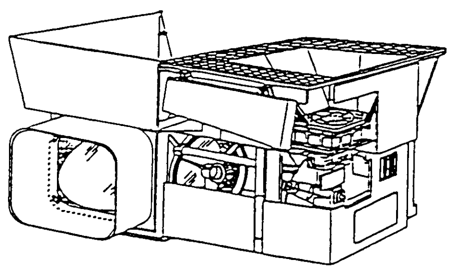


Figure 2 Imager Sensor Module

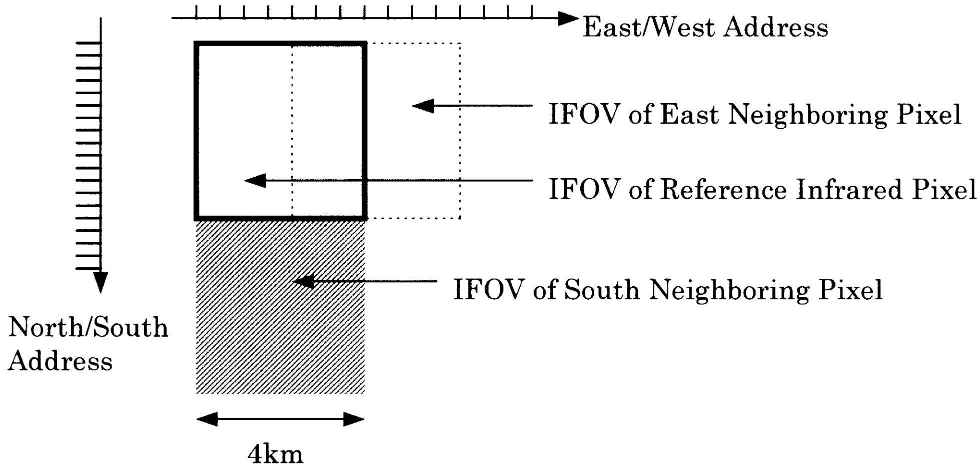


Figure 3 Infrared Pixel and Address

3. Over-sampling Imagery

A large overlap area between two neighboring pixels is generated in the east/west direction because the IFOV size of infrared channels is 4 km while the ground sampling distance is 2.3 km. This kind of imagery, which is sampled by a narrower distance than the IFOV size is called "over-sampling imagery" in this report. There is normally no over-sampling in the north/south direction for the MTSAT Imager because the IFOV size and the north-south step size are both 4 km.

Conceiving of the over-sampling imagery in the frequency domain helps to understand what it means. Figure 4 shows Modulation Transfer Function (MTF) in the north/south and east/west. An east-west image signal is band-limited less than the Nyquist frequency because the signal is over-sampled. On the other hand, the absence of over-sampling in the north/south direction provides response in higher frequency than the Nyquist frequency. Thus, aliasing appears in a north/south image signal and it is not possible to reconstruct an original image signal.

Now if an image is over-sampled in the north/south direction, the Nyquist frequency of the north/south moves to higher frequency and the aliasing is solved. Thus, it is possible to convert the IFOV (i.e. Point Spread Function) using the Digital Signal Processing.

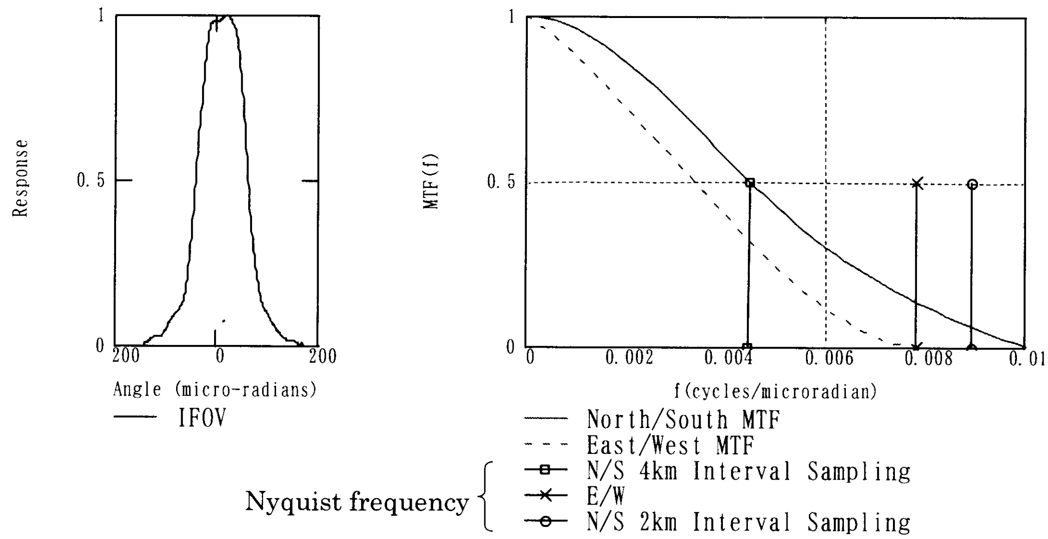


Figure 4 Imager MTF and PSF

The over-sampling image is generated by a combination of two images simply. As mentioned above, the scan start position of an image in the north/south direction is specified by 8 micro-radians. Here, it is proposed to acquire a series of two images; the position and size of the second image is the same as the first image except for a north/south scan start position offset. The difference of the north/south scan start positions is a half infrared pixel (i.e. 56 micro-radians). Then incorporating the first image with the second alternately, shown in Figure 5, generates the over-sampling image.

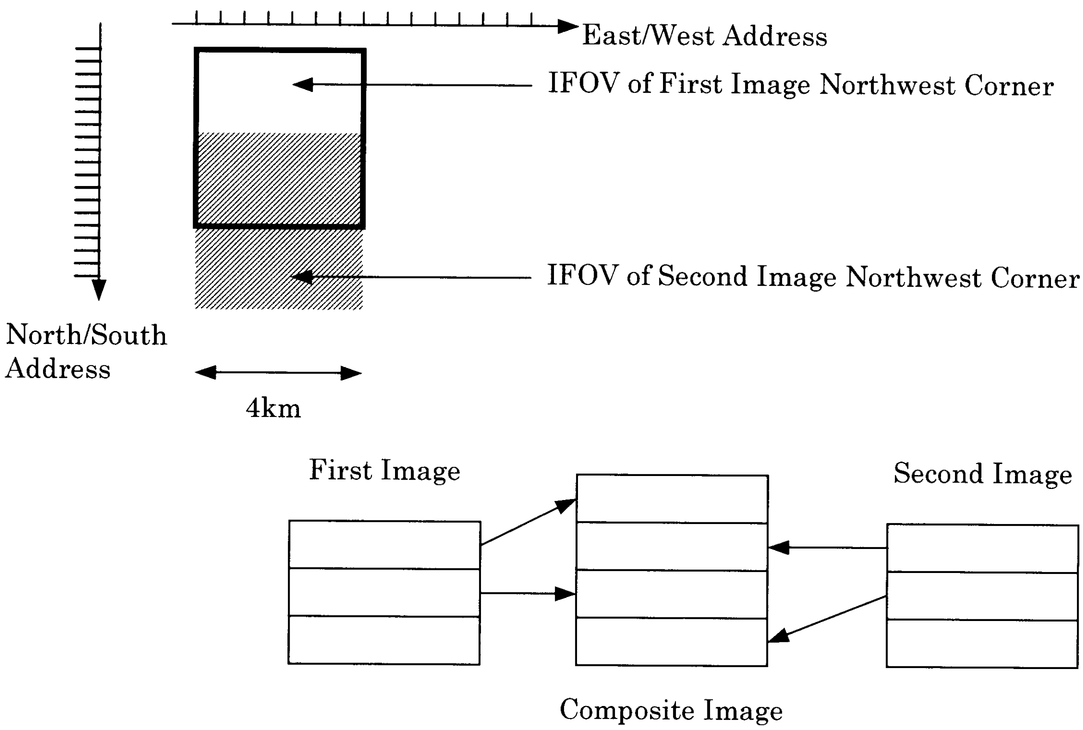


Figure 5 Generation of Over-sampling Imagery using MTSAT Imager

4. Filter for Enhancing

The digital filter that is used for enhancing the over-sampling image is generated by the ratio of a 2 km-IFOV MTF to a 4 km-IFOV MTF. Figure 6 shows the process of making the filter.

5. Verification by AVHRR Image

The filter for enhancing was verified using AVHRR images. A 2 km IFOV image and 4 km IFOV image are simulated by the AVHRR infrared image that has 1.1 km resolution at nadir for the verification of the effect of the enhancing filter.

Figure 7 shows the flow of the verification. Squares (□) in the figure show the size of IFOV, small dots (・) mean the sampling points of a 1 km image, and circles (●) the sampling points of a 2 km image. The over-sampling image has 4 km IFOV and is enhanced by the 2 km to 4 km MTF ratio filter (Operator C shown in Figure 8) described above.

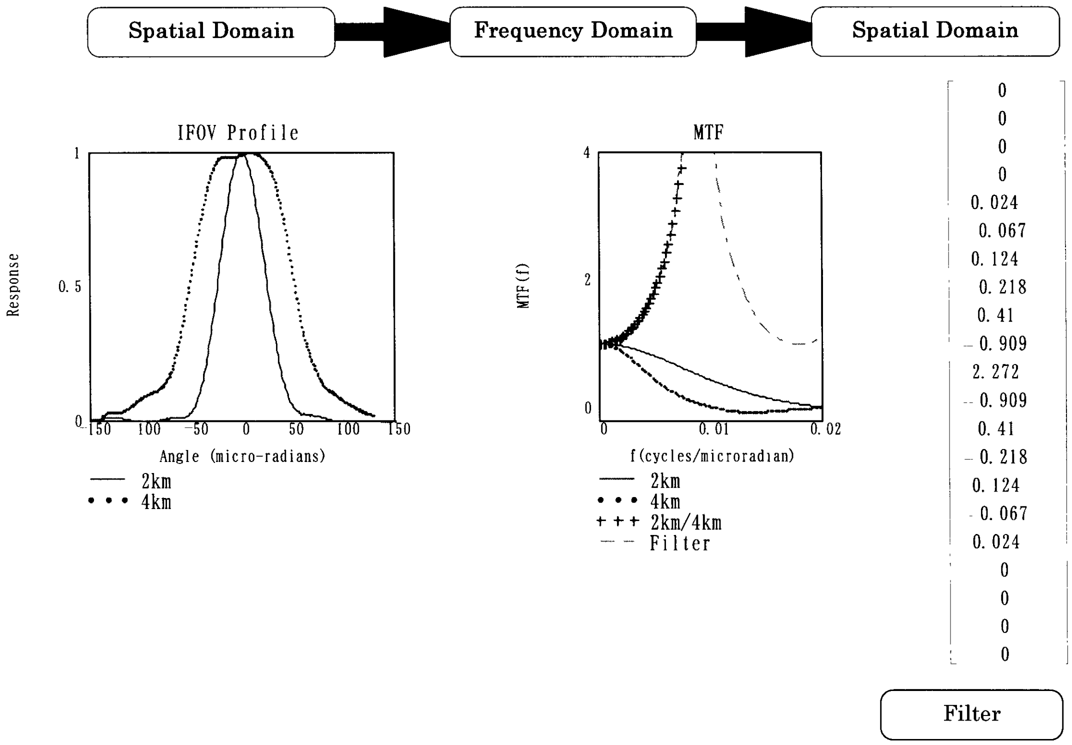


Figure 6 Process of Making Filter for Enhancing

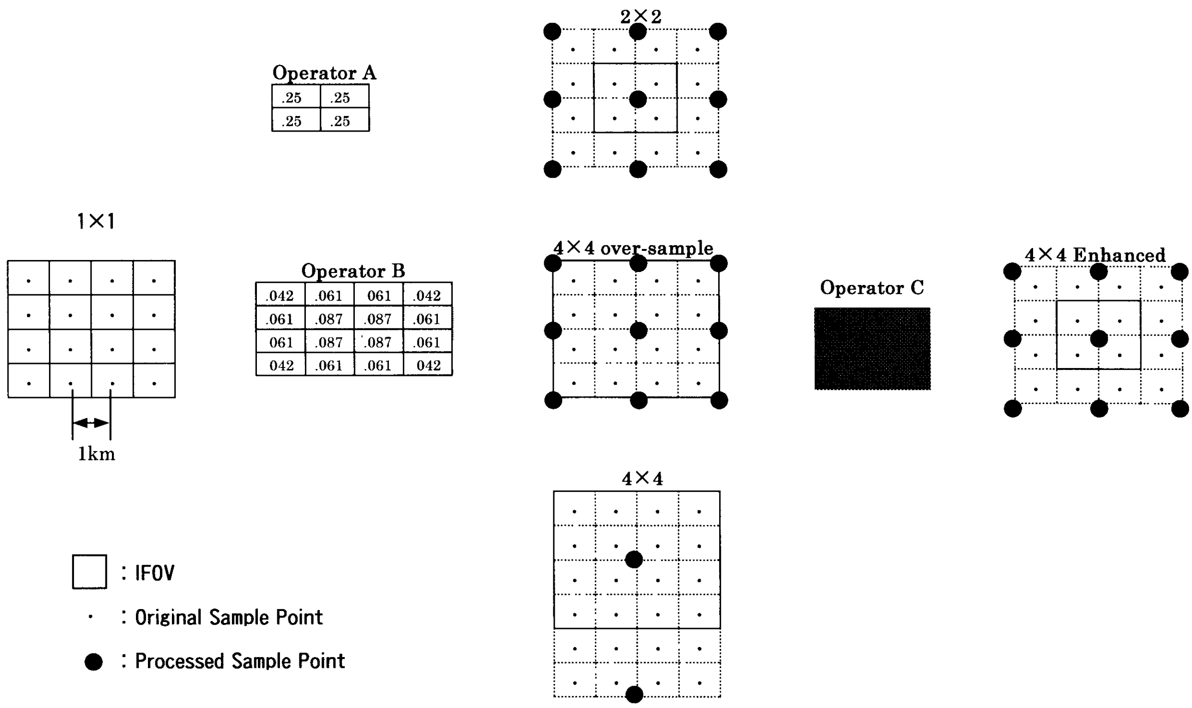


Figure 7 Verification Flow using AVHRR Image

Operator B (1 × 1=>4 × 4)

0.042	0.061	0.061	0.042
0.061	0.087	0.087	0.061
0.061	0.087	0.087	0.061
0.042	0.061	0.061	0.042

Operator C (4 × 4=>2 × 2)

0.004	-0.005	0.008	-0.012	0.020	-0.036	0.106	-0.036	0.020	-0.012	0.008	-0.005	0.004
-0.005	0.008	-0.012	0.018	-0.029	0.053	-0.155	0.053	-0.029	0.018	-0.012	0.008	-0.005
0.008	-0.012	0.018	-0.027	0.043	-0.078	0.229	-0.078	0.043	-0.027	0.018	-0.012	0.008
-0.012	0.018	-0.027	0.040	-0.065	0.119	-0.348	0.119	-0.065	0.040	-0.027	0.018	-0.012
0.020	-0.029	0.043	-0.065	0.104	-0.191	0.560	-0.191	0.104	-0.065	0.043	-0.029	0.020
-0.036	0.053	-0.078	0.119	-0.191	0.351	-1.028	0.351	-0.191	0.119	-0.078	0.053	-0.036
0.106	-0.155	0.229	-0.348	0.560	-1.028	3.007	-1.028	0.560	-0.348	0.229	-0.155	0.106
-0.036	0.053	-0.078	0.119	-0.191	0.351	-1.028	0.351	-0.191	0.119	-0.078	0.053	-0.036
0.020	-0.029	0.043	-0.065	0.104	-0.191	0.560	-0.191	0.104	-0.065	0.043	-0.029	0.020
-0.012	0.018	-0.027	0.040	-0.065	0.119	-0.348	0.119	-0.065	0.040	-0.027	0.018	-0.012
0.008	-0.012	0.018	-0.027	0.043	-0.078	0.229	-0.078	0.043	-0.027	0.018	-0.012	0.008
-0.005	0.008	-0.012	0.018	-0.029	0.053	-0.155	0.053	-0.029	0.018	-0.012	0.008	-0.005
0.004	-0.005	0.008	-0.012	0.020	-0.036	0.106	-0.036	0.020	-0.012	0.008	-0.005	0.004

Operator(Operator B * Operator C)

0.014	-0.023	-0.049	-0.049	-0.023	0.014
-0.023	0.039	0.083	0.083	0.039	-0.023
-0.049	0.083	0.176	0.176	0.083	-0.049
-0.049	0.083	0.176	0.176	0.083	-0.049
-0.023	0.039	0.083	0.083	0.039	-0.023
0.014	-0.023	-0.049	-0.049	-0.023	0.014

Operator A (1 × 1=>2 × 2)

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0.25	0.25	0	0
0	0	0.25	0.25	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Figure 8 Filter for Enhancing (Operator C)

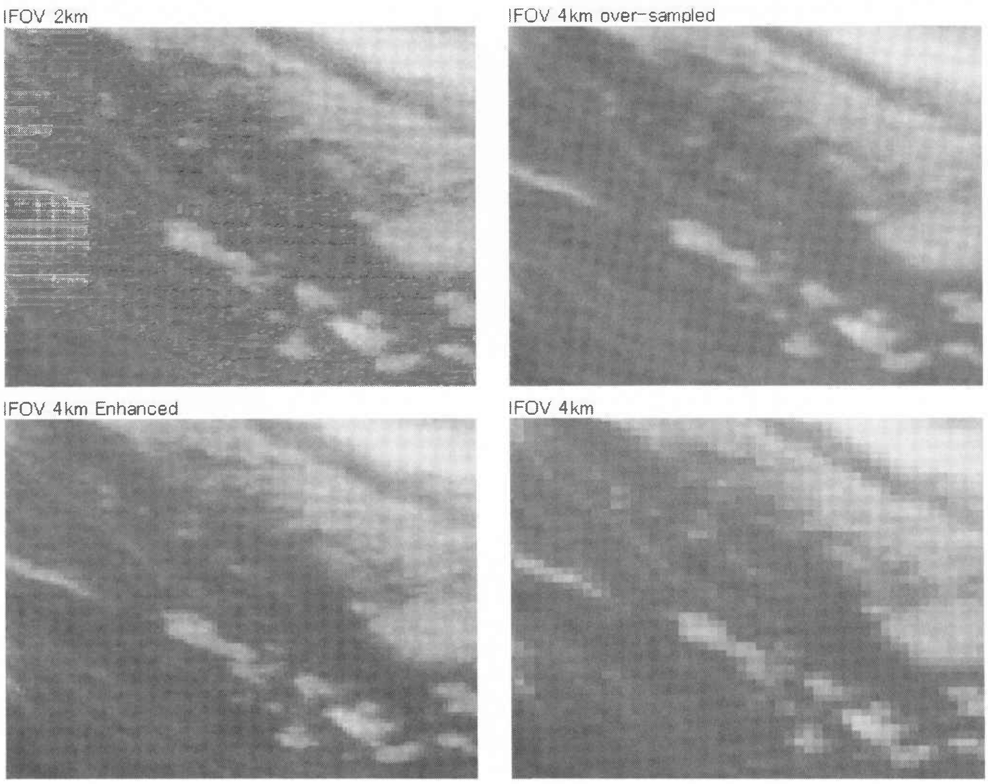


Figure 9 Simulation Results using AVHRR Image

Figure 9 shows simulation results as images. The over-sampling image shows the details of the clouds better than the original image due to the over-sampling image has having four times as many pixels as the original. Brightness level on the enhanced image is like that on the 2 km IFOV image, verifying that the enhancing filter has been generated successfully.

6. Cloud Motion Impact

Two or more images produce the over-sampling image. It is unavoidable to have a time lag of scanning between these source images, and the time lag has an impact on the over-sampled, composite image. The cloud motion caused by the time lag should be considered in the process. Now the cloud motion is considered using one-dimensional discussion.

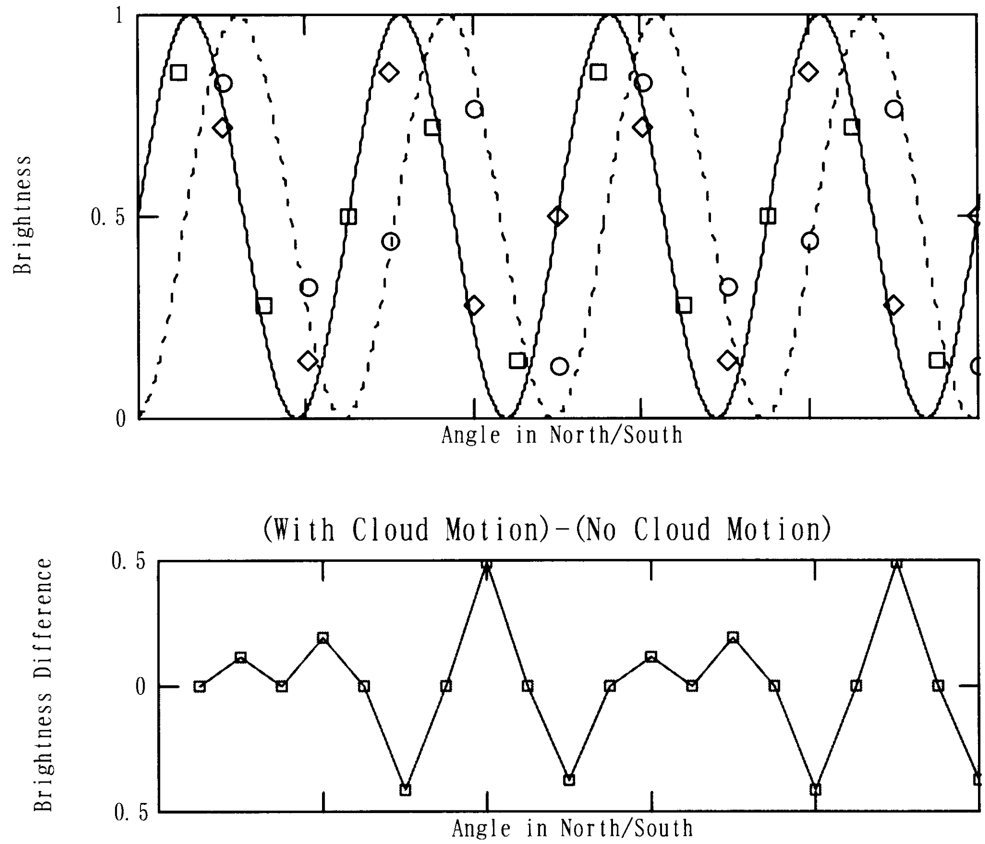


Figure 10 Example of Error due to Cloud Motion

Figure 10 shows the north/south brightness level of the over-sampling image that is generated by two source images. The source images are observed by a rectangular IFOV. On the upper graph, a solid line shows input (i.e. cloud pattern) for the first image, and a dotted line for the second. Squares (□) mean the brightness of the first image, circles (○) the second image. If there should be no change of the cloud pattern between these images, the second image appears with diamonds (◇) . On the lower graph, the difference of the brightness between the over-sampling image with a change of the cloud pattern (i.e. cloud motion) and that without the cloud motion is shown. This shows that an error from the Nyquist frequency through 1/2 Nyquist frequency is generated on the over-sampling image if the cloud motion appears. The error is enhanced by the enhancing filter, and causes a marked stripe in the north/south direction. Thus, a low-pass filter is required to eliminate the stripe generated by the cloud motion.

7. On-orbit Demonstration

MTSAT will be launched in geostationary orbit around August 1999. On-orbit testing for the Imager is scheduled from September through November 1999. During the testing, the over-sampling image will be acquired for the verification of image navigation accuracy. A few hundreds of the over-sampling images have the size of 1000 km east/west and 500 km north/south will be available for the navigation verification and an assessment of the cloud motion wind.

8. GOES-10 On-orbit Demonstration

A preliminary demonstration of the over-sampling imagery collection concept was conducted using the GOES-10 Imager during the spacecraft post-launch test period in October 1997. The GOES-10 Imager provides a valid proof-of-concept because its IFOV and scan system design is identical to that of the MTSAT Imager.

The GOES-10 test produced imagery oversampled in the east-west direction by the nominal 2.3 km sampling interval to 4 km IFOV ratio. Over-sampling in the north-south direction was accomplished by collecting a series of three images that together produce a composite image with 2 km north-south sampling. The first image was a 1000 km (east-west) by 250 km (north-south) image. The second was a 1000 km by 500 km image offset from the first image by 2 km (one-half pixel) in the north-south direction. The last image was a 1000 km by 250 km frame with its north-south start address equal to the stop address of the first frame.

Together the first and third images produce a 1000 km by 500 km image that is offset from the second image by a half pixel. By collecting two 1000 km by 250 km images (instead of a 1000 km by 500 km frame), the effect of cloud motion is minimized because less time has elapsed between the collection of the first image and the top half of the second image and also between the bottom half of the second image and the third.

This image sequence was repeated at three different geographical locations in order to provide a variety of image content. The GOES-10 data was used to develop and demonstrate the image analysis techniques presented here.

The details of GOES-10 on-orbit testing are described in Appendix A.

9. Conclusion

The essence of this study is the use of an existing imaging system to demonstrate the effect of 2 km infrared images. The study has established a method of making the enhancing filter, a technique of making the over-sampling image, a procedure of image acquisition, and so on. Testing environment such as image processing software will be prepared for the on-orbit demonstration after this.

オーバサンプリング画像の調査

このレポートでは、運輸多目的衛星イメージャの水平分解能を向上させる可能性を調査した結果を解説している。
運輸多目的衛星に搭載されるイメージャの水平分解能は、赤外チャンネルが４km、可視チャンネルが１kmである。このイメージャによって取得される複数の画像を合成することにより、画素の間隔を赤外チャンネルで２kmにすることが可能である。さらに、デジタル画像処理を用いて、合成した画像を強調することにより、水平分解能が２kmの赤外チャンネルに近い画像を得ることができる。このレポートでは、軌道上での実証試験についても解説する。

Appendix A GOES-10 On-orbit Demonstration

1. Purpose of This Document

This document describes the details of GOES-10 on-orbit testing for over-sampling concept.

2. Test Sequence

Table A-1 shows the sequence of the over-sampling testing using GOES-10 Imager.

The testing was performed with IMC (Image Motion Compensation) off because IMC generates a compensation signal to produce an image with fixed earth projection.

The MMC (Mirror Motion Compensation) that compensates for the effects on the rigid body portion of the Imager and Sounder scan mirror motions was on.

The Sounder was idle and without sounding.

Table A-1 GOES-10 Over-sampling Test Sequence

Configure for test
- IMC off
- MMC on
- Sounder idle

Execute test frames
- Sequence A:
  - #1 1000km East/West x 250km North/South frame
  - #2 1000km East/West x 500km North/South frame
    => start address offset 56 micro-radians to north of #1
  - #3 1000km East/West x 250km North/South frame
    => start address equal to North/South stop address of #1
  - #4 same as #1
  - #5 same as #2
  - #6 same as #3
- Sequence B: change geographic location and repeat from #1 through #6
- Sequence C: change geographic location and repeat from #1 through #6

Table A-2 Location and Time of Test Frames

Sequence A : Florida
10/28/97 18:41:41-18:44:10UTC
Sequence B : Baja California
10/28/97 18:47:41-18:50:12UTC
Sequence C : San Francisco Bay
10/28/97 18:53:41-18:56:16UTC

The test included three imaging sequences acquired at different geographical locations in order to provide a variety of image content. The geographical location and imaging time of the each sequence are shown in Table A-2.

At each geographical location, a series of three images was repeated with the result that each imaging sequence had 6 images.

Regarding the series of three images, the first image was a 1000 km (east-west) by 250 km (north-south) image. The second was a 1000 km by 500 km image offset from the first image by 2 km (one-half pixel) in the north-south direction. The last image was a 1000 km by 250 km frame with its north-south start address equal to the stop address of the first frame.

Figure A-1 shows a snap shot of Sequence A; Florida.

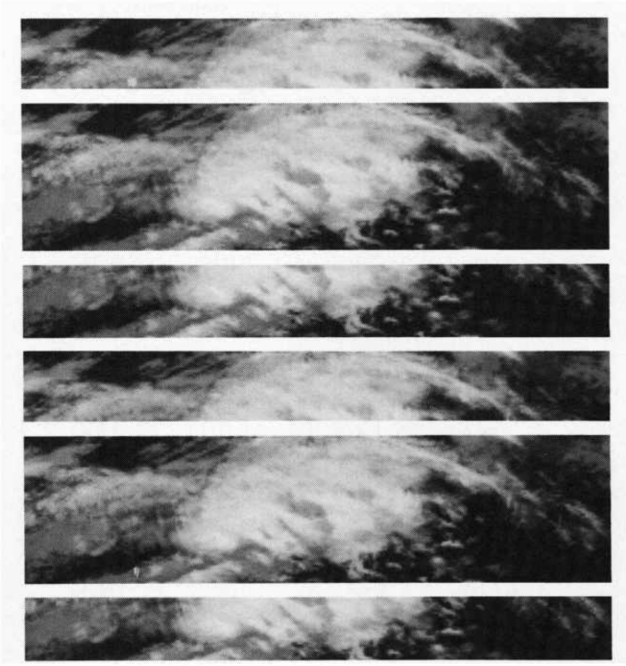


Figure A-1 Snap Shot of Sequence A

3. Image Processing

The first step of image processing using GOES-10 Imager data is to merge the three images together. Together the first and third images produce a 1000 km by 500 km image that is offset from the second image by a half infrared pixel.

The second step is to remove image stripes in channel 4 (10.7 micro-meter) and 5 (12 micro-meter). The stripes are caused by differences in the outputs of the two detectors[1].

A striping index with counts is measured, then the de-striping of the merged images is performed by adjusting image counts using the measured striping index. Figure A-2 shows the effect of the de-striping in the merged image.

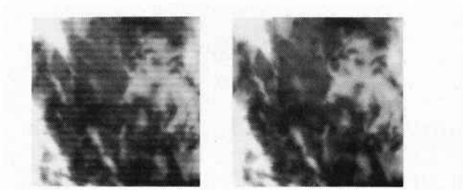


Figure A-2 De-striping

The third step is the enhancement of the merged image that has a 2.3 km (east-west) by 2 km (north-south) lattice. The enhancement is processed using spatial domain digital filters that are generated by MTF ratio. Table A-3 shows the digital filters for GOES-10 image enhancement.

Channel 2 (3.8-4.0 micro-meter)		Channel 4 (10.2-11.2 micro-meter)		Channel 5 (11.5-12.5 micro-meter)	
West	North	West	North	West	North
-0.002	-	-	-	-	-
0.003	-	-	-	-	-
0.003	-	-	-	-	-
-0.027	-	-	-	-	-
0.090	-	-0.001	-	-	-
-0.189	-	0.005	0.047	0.019	0.019
0.442	0.045	-0.016	-0.066	-0.026	-0.027
-0.660	-0.106	0.021	0.217	0.045	0.041
0.924	0.225	0.123	-0.285	-0.074	-0.102
-1.219	-0.582	-0.664	-0.398	-0.207	-0.182
2.301	1.836	1.987	1.971	1.704	1.594
-1.086	-0.582	-0.464	-0.398	-0.413	-0.261
0.639	0.225	-0.063	-0.285	-0.369	-0.215
-0.400	-0.106	0.101	0.217	0.344	0.147
0.243	0.045	-0.038	-0.066	-0.077	-0.047
-0.106	-	0.010	0.047	0.055	0.033
0.060	-	-0.002	-	-	-
-0.019	-	-	-	-	-
0.005	-	-	-	-	-
0.001	-	-	-	-	-
-0.002	-	-	-	-	-
East	South	East	South	East	South

Table A-3 Digital Enhancement Filters for GOES-10 Imager

The final step is to remove the high spatial frequency caused by cloud motion in images. The following low-pass filter is used for the images to be enhanced in the north-south direction. An examination into the low-pass filter is described later.

0.001
-0.003
0.007
-0.011
0.010
0.003
-0.035
0.083
-0.136
0.178
0.807
0.178
-0.136
0.083
-0.035
0.003
0.010
-0.011
0.007
-0.003
0.001

Table A-4 Low Pass Filter

4. Photos

The processed images of the GOES-10 over-sampling testing are shown from Figure A-3 through A-8. Each figure includes three images; the processed image latticed with 2.3 km in the east-west by 2 km in the north-south (top), the current GOES image latticed with 2.3 km east-west by 4 km north-south (middle), and the simulated MTSAT HiRID (High Resolution Imager Data, i.e. processed data for users) latticed with 4.6 km east-west by 4 km north-south.

There are two missing lines in the original image of GOES-10, and so an unusual image pattern is shown in the middle of the image to be enhanced.

Figure A-6 through A-8 show a difference in brightness temperature between Channel 4 and 5, whose white areas indicate that the temperature difference (Channel 4 - 5) is high. Note that the calibration coefficients don't have operational accuracy, so that a quantitative analysis is limited.

5. Image Analysis

Figure A-9 through A-11 show the maximum and minimum temperatures in the processed versus current GOES images on 8 pixels (east-west) by 10 pixels (north-south) in the enhancing image, i.e., approximately 20 km square. Circular marks (maximum temperature) appear over a diagonal line of the figures, and triangular marks (minimum temperature) under the line. This means that the temperature range of the processed image is expanded as compared with the current GOES image. In general, it is supposed that a higher spatial resolution image provides more chances to observe the high emissivity part of cirrostratus, that is the minimum temperature appears lower, and more chances to reduce the cloud contamination of clear sky radiance in IFOV, so that the maximum temperature appears higher. Figure A-9 through A-11 indicate no inconsistency of the above supposition. It is noticeable that the minimum temperature difference of the processed image shown in Figure A-9.b, A-10.b, and A-11.b appears closer to 0 K. This gives a proof that the higher emissivity part is observed in the processed image.

Table A-5 shows low-pass filters to reduce the high spatial frequency in the image caused by the cloud motion. Figure A-12 shows the frequency response of the low-pass filters shown in Table A-5. For the purpose of comparing the effect of the low-pass filters, a difference of the maximum and minimum temperatures between the enhancing and current GOES images shown in Figure A-9 is calculated by each low-pass filter. The average of the difference is shown in Figure A-13.

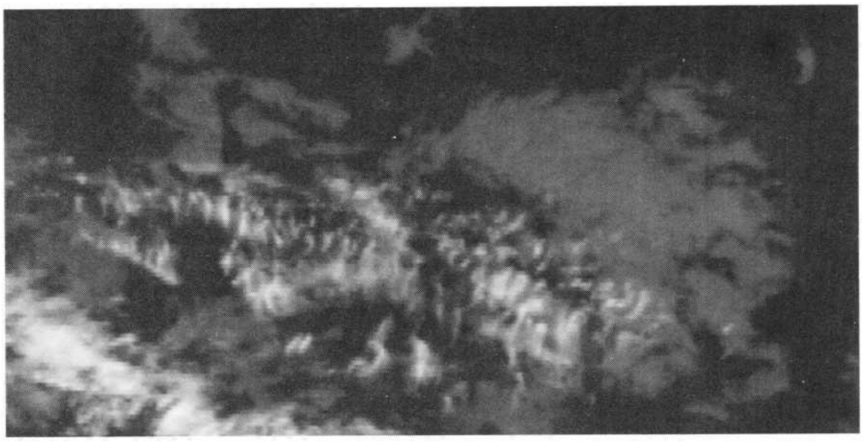
Table A-6 shows the standard deviation of the clear sky area ranging approximately 20 km square on channel 4. The ratio of the processed to current GOES images is about 3:1. It is presumed that image noise is enhanced by the enhancing digital filters, so that the high standard deviation of the processed image is observed. To verify this presumption, the image noise generated by Gaussian and 1/f noise[2] was simulated, and enhanced. The simulated noise increased twofold or threefold by the enhancing filters. Thus, it is possible to explain that the standard deviation shown in Table A-6 indicates the enhancement of the image noise.

Processed

Current GOES

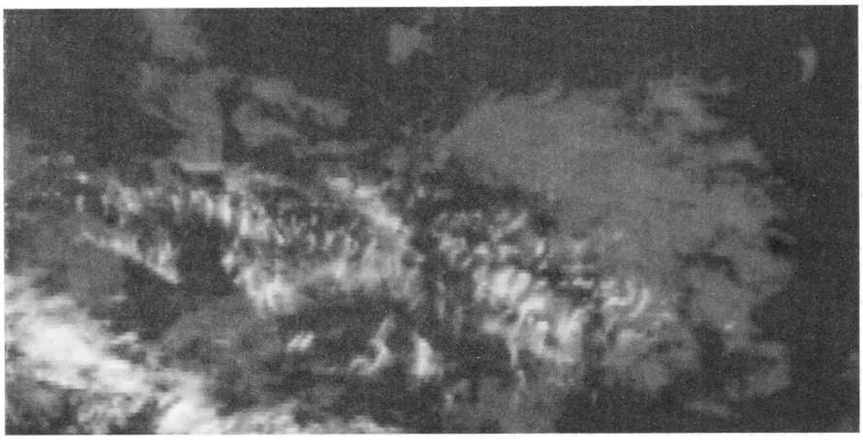
MTSAT HiRID

Figure A-3 GOES-10 Over-sampling Testing
Florida Channel 4
10/28/97 18:41-18:44 UTC
NASA, NOAA, S.Kigawa(JMA)



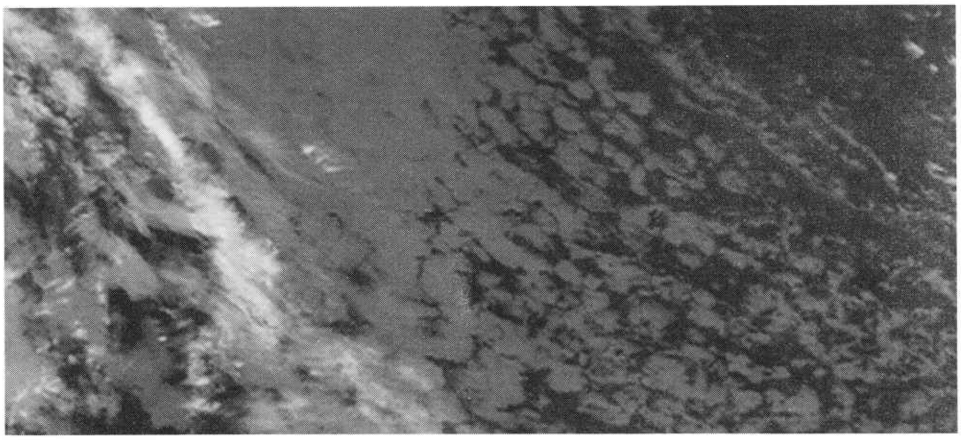
Processed

Current GOES

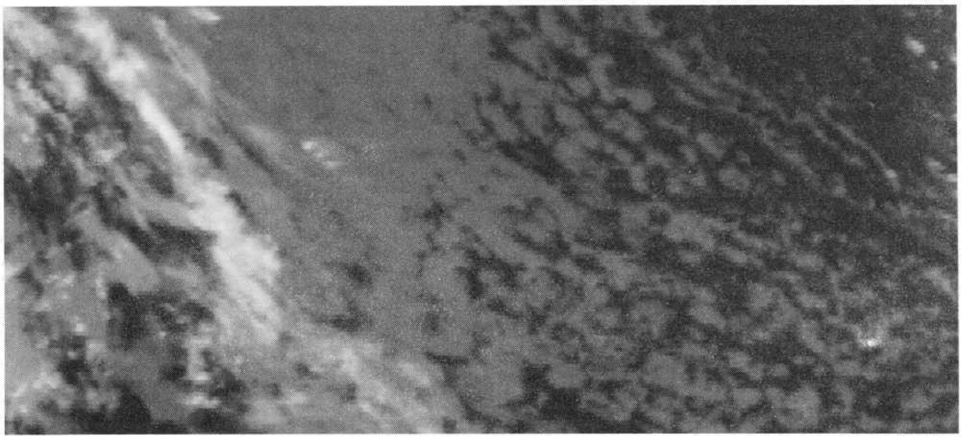


MTSAT HiRID

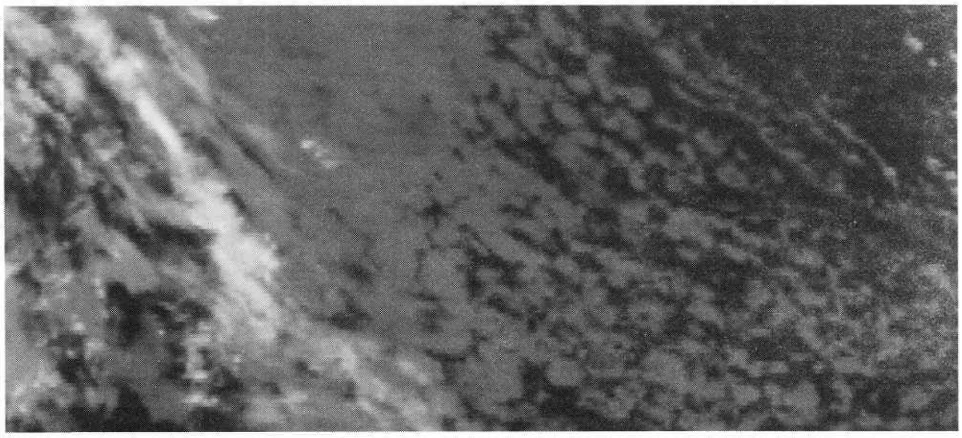
Figure A-4　GOES-10 Over-sampling Testing
Baja California Channel 4
10/28/97 18:47-18:50 UTC
NASA, NOAA, S.Kigawa(JMA)



Processed

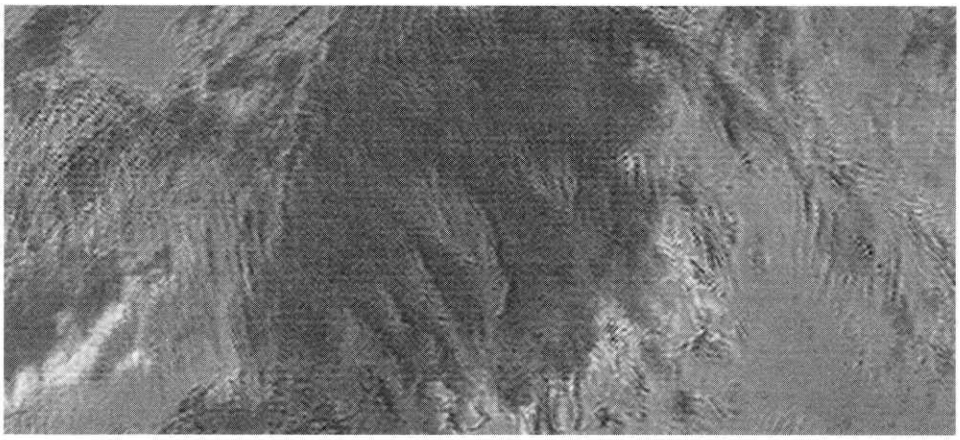


Current GOES

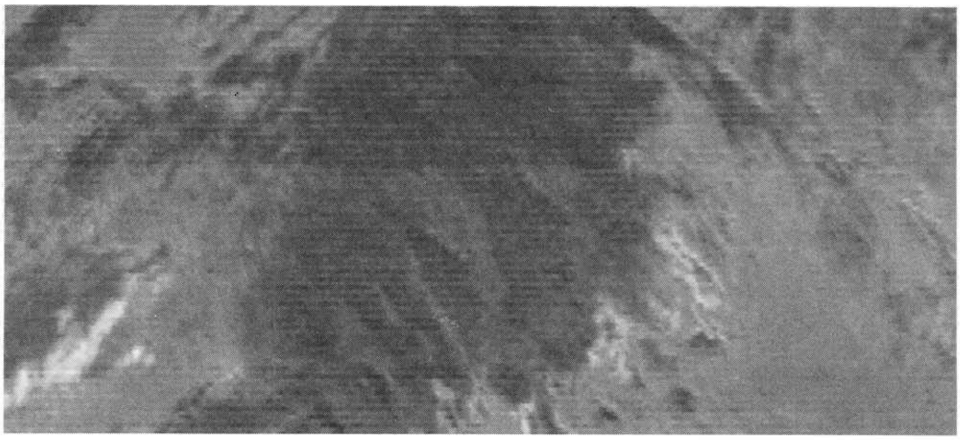


MTSAT HiRID

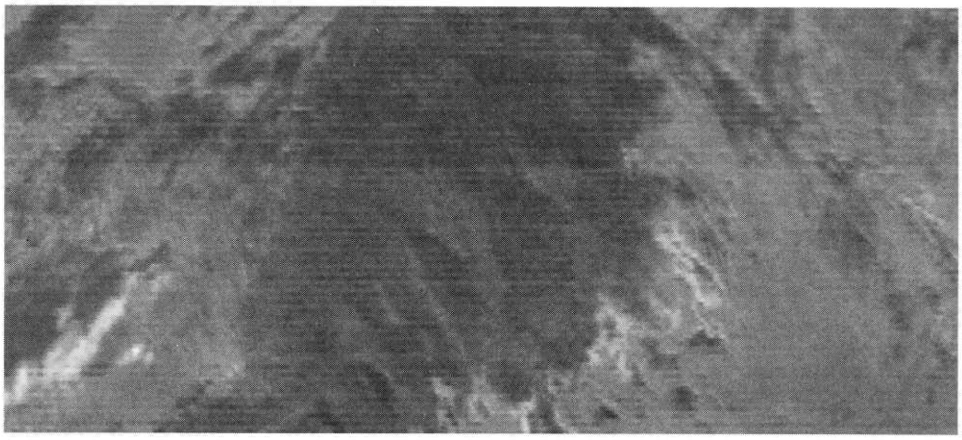
Figure A-5 GOES-10 Over-sampling Testing
San Francisco Bay Channel 4
10/28/97 18:53-18:56 UTC
NASA, NOAA, S.Kigawa(JMA)



Processed

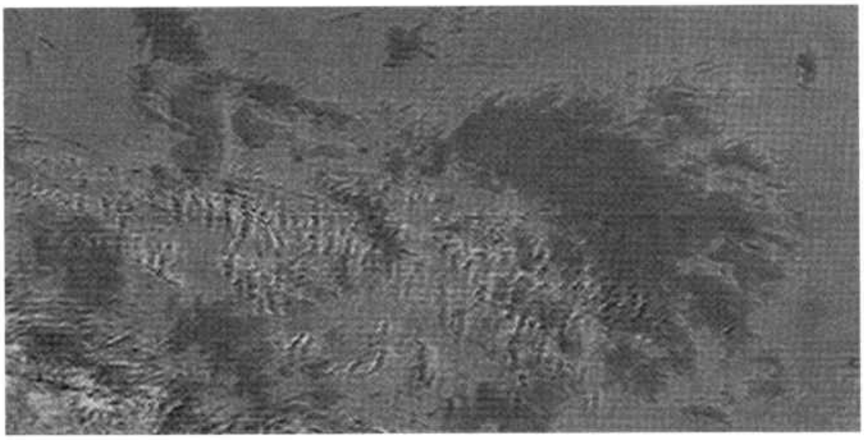


Current GOES

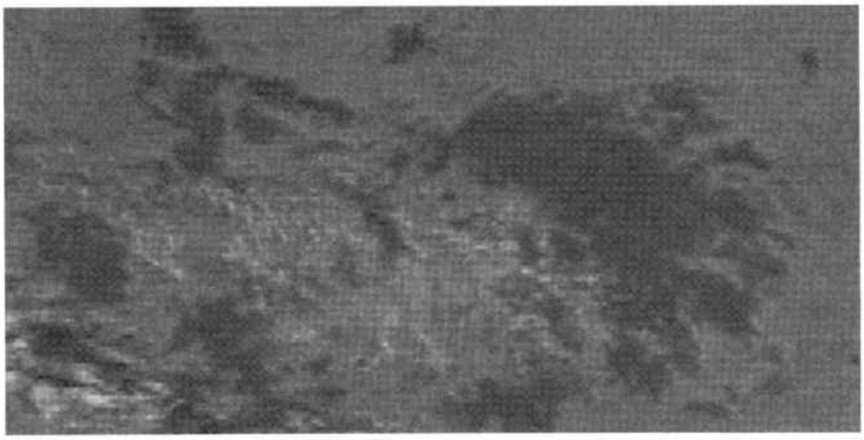


MTSAT HiRID

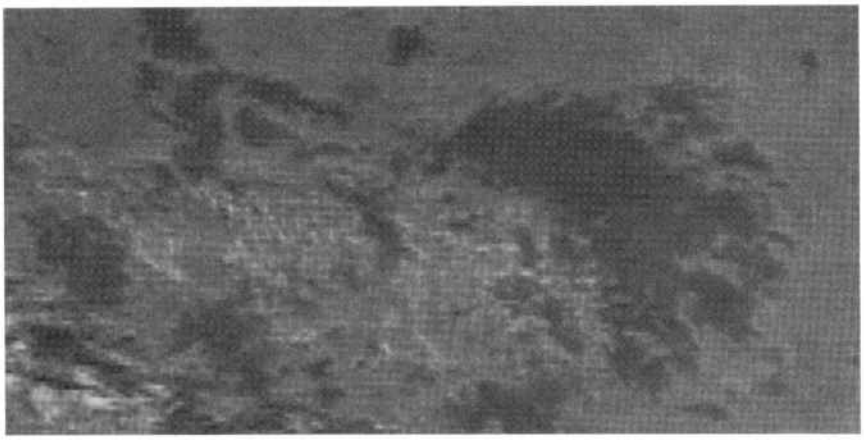
Figure A-6　GOES-10 Over-sampling Testing
Florida Channel 4 − Channel 5
10/28/97 18:41-18:44 UTC
NASA, NOAA, S.Kigawa(JMA)



Processed

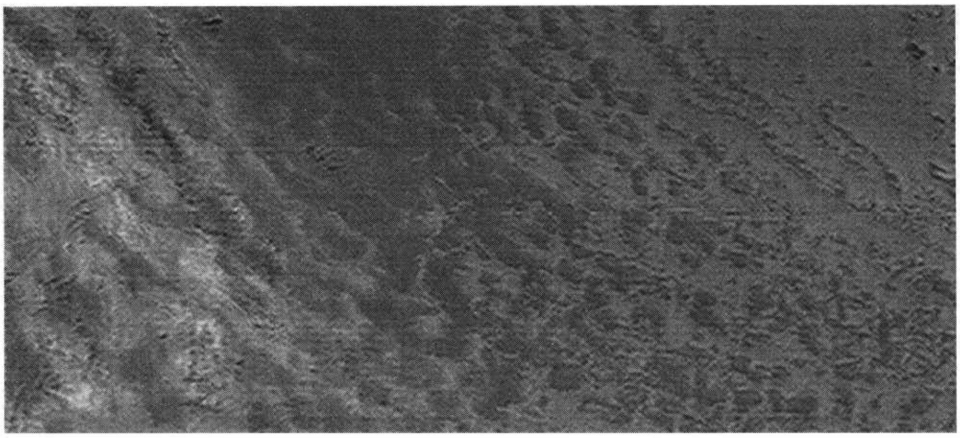


Current GOES

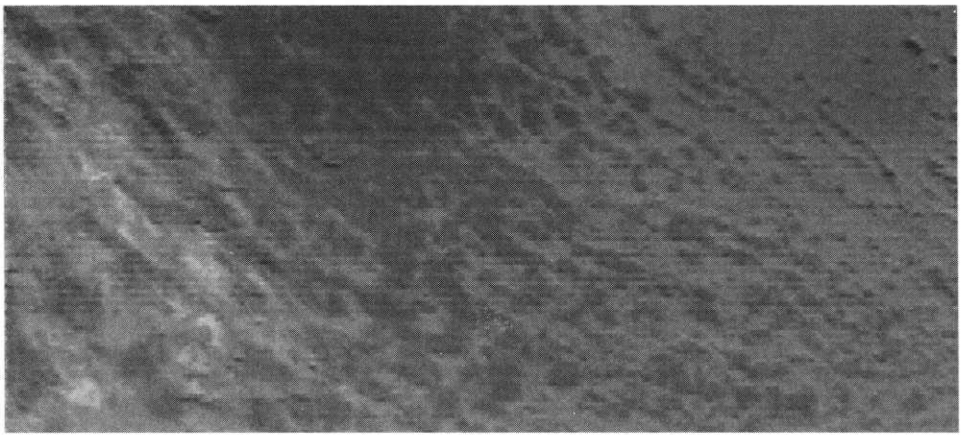


MTSAT HiRID

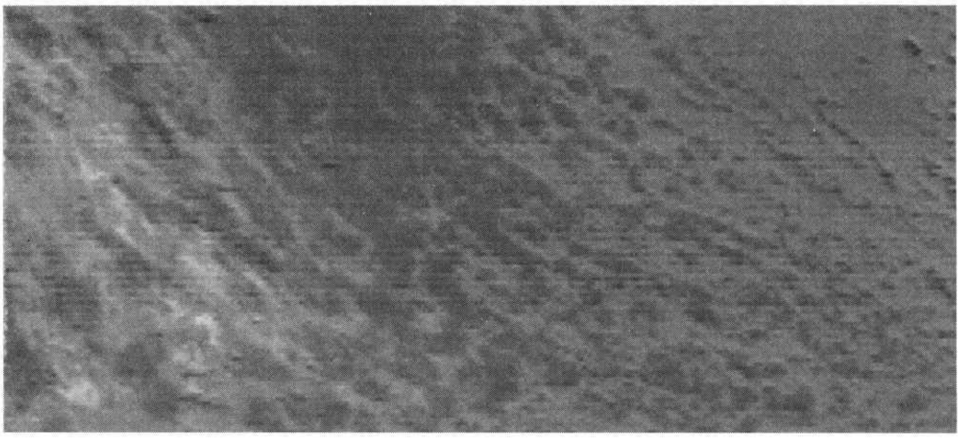
Figure A-7 GOES-10 Over-sampling Testing
Baja California Channel 4 − Channel 5
10/28/97 18:47-18:50 UTC
NASA, NOAA, S.Kigawa(JMA)



Processed

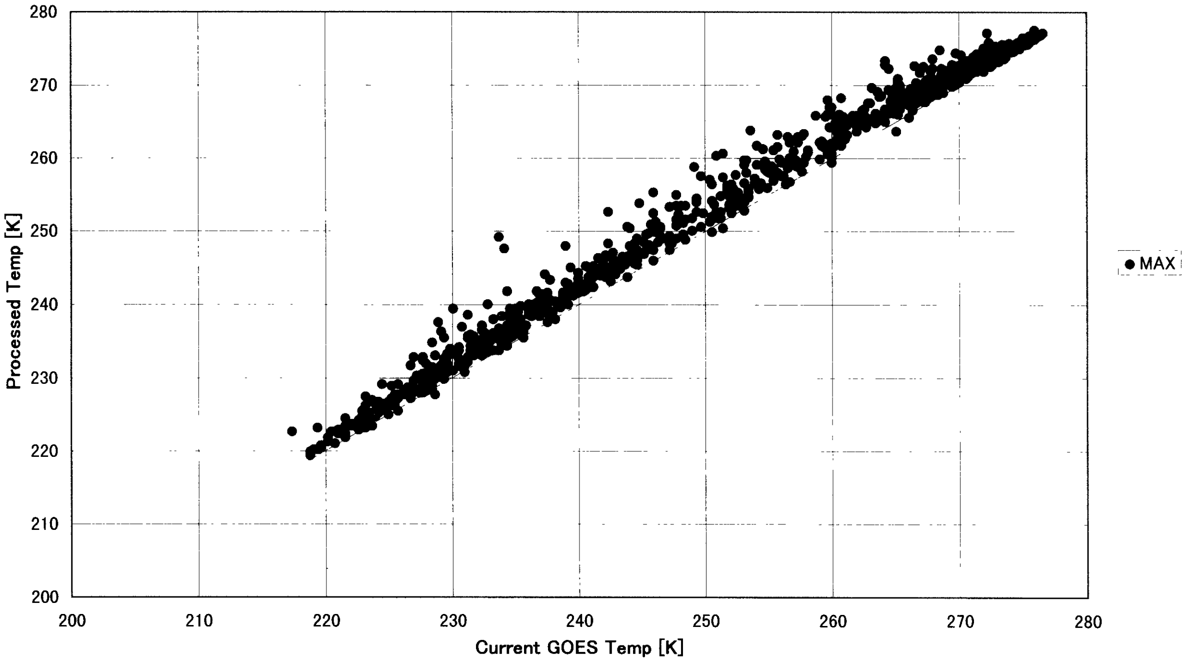


Current GOES



MTSAT HiRID

Figure A-8　GOES-10 Over-sampling Testing
San Francisco Bay Channel 4 − Channel 5
10/28/97 18:53-18:56 UTC
NASA, NOAA, S.Kigawa(JMA)



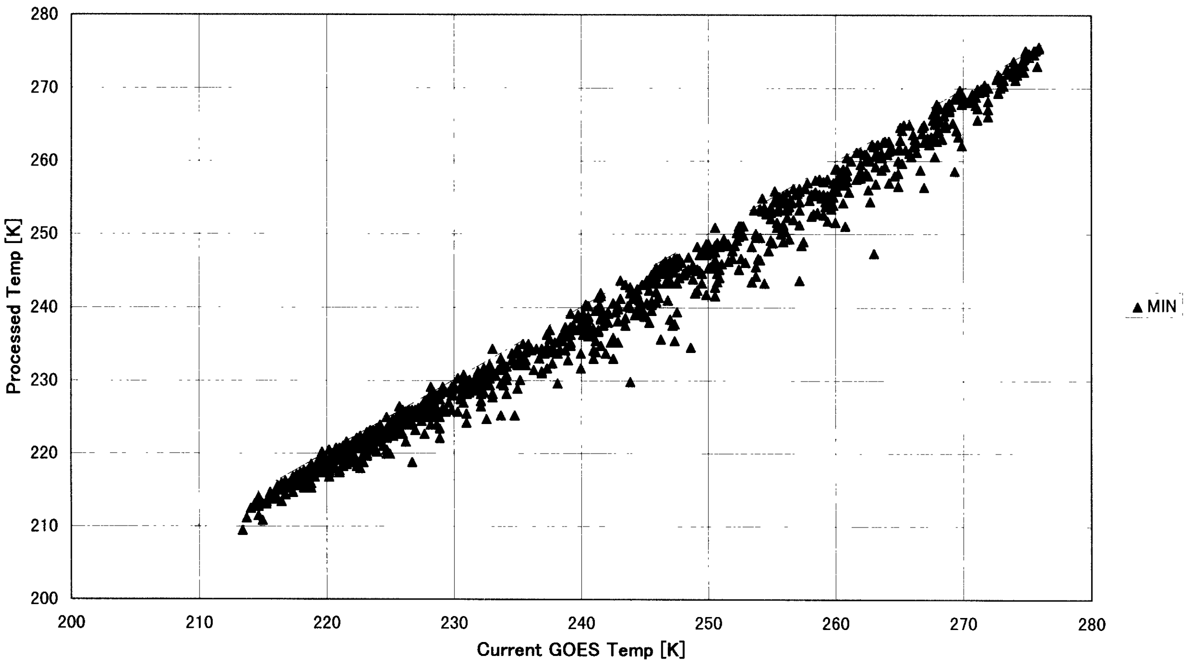
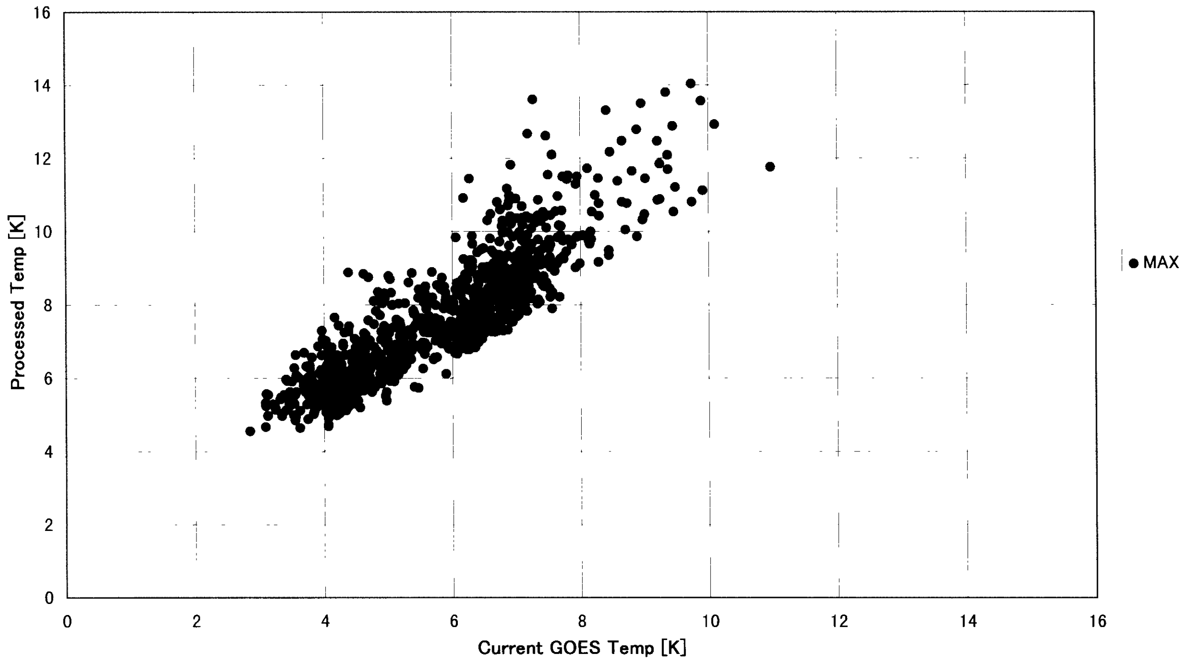


Figure A-9.a Maximum(Top) and Minimum(Bottom) Temperatures of Florida, Channel 4



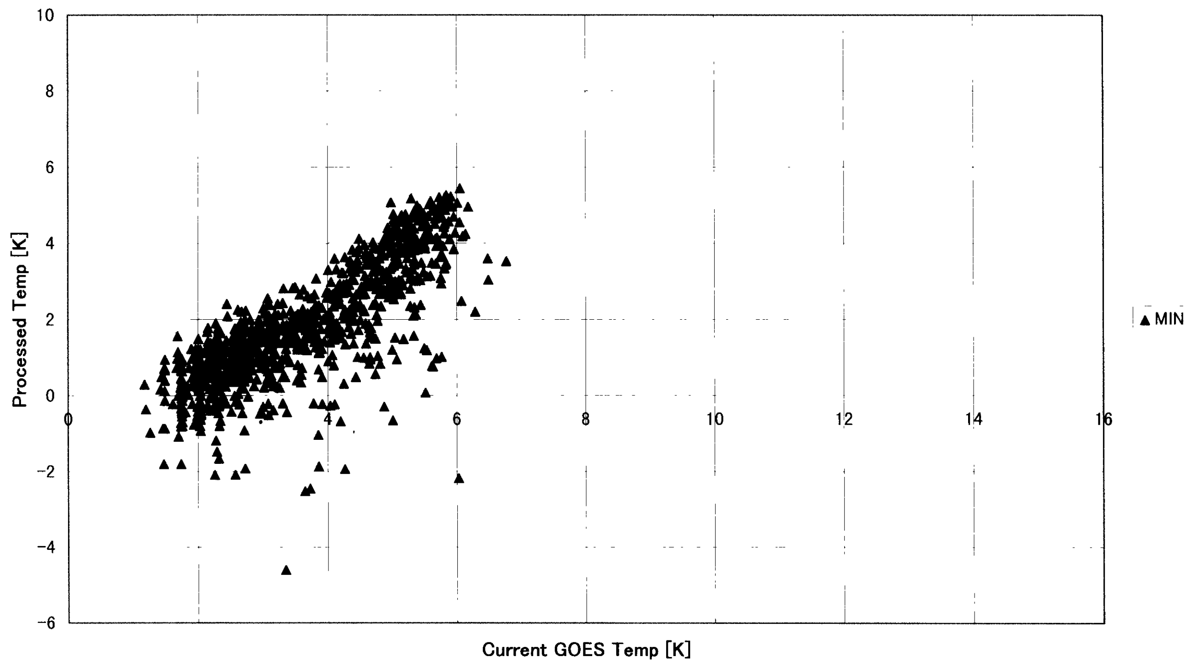
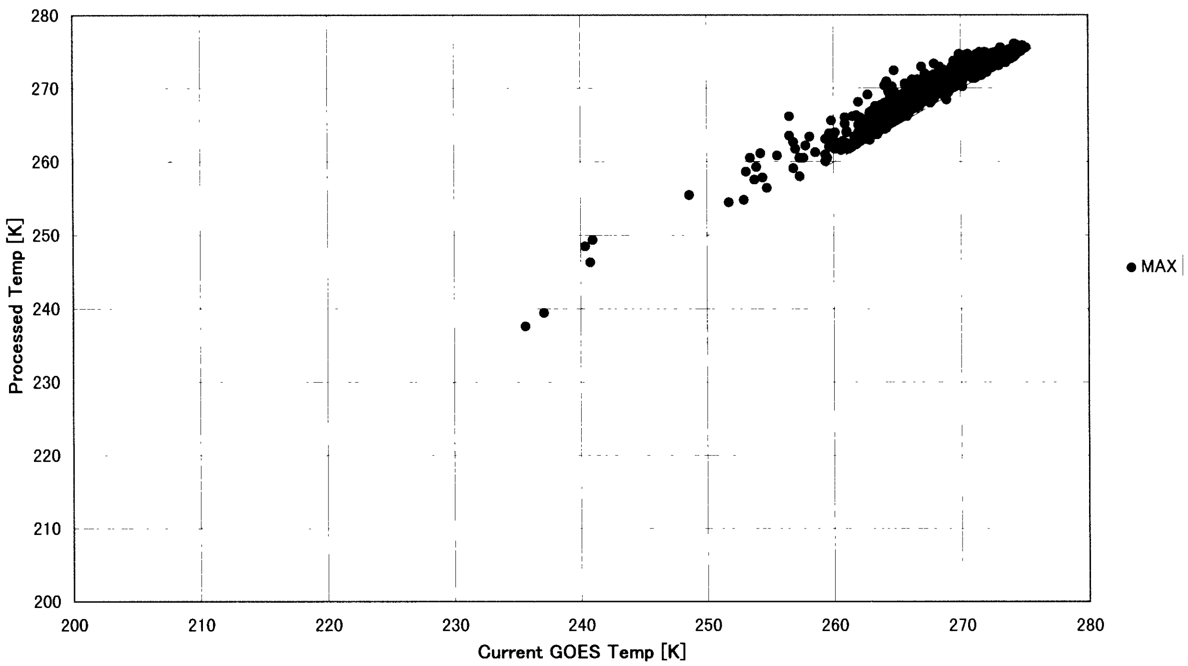


Figure A-9.b　Maximum(Top) and Minimum(Bottom) Temperatures of Florida, Channels 4-5



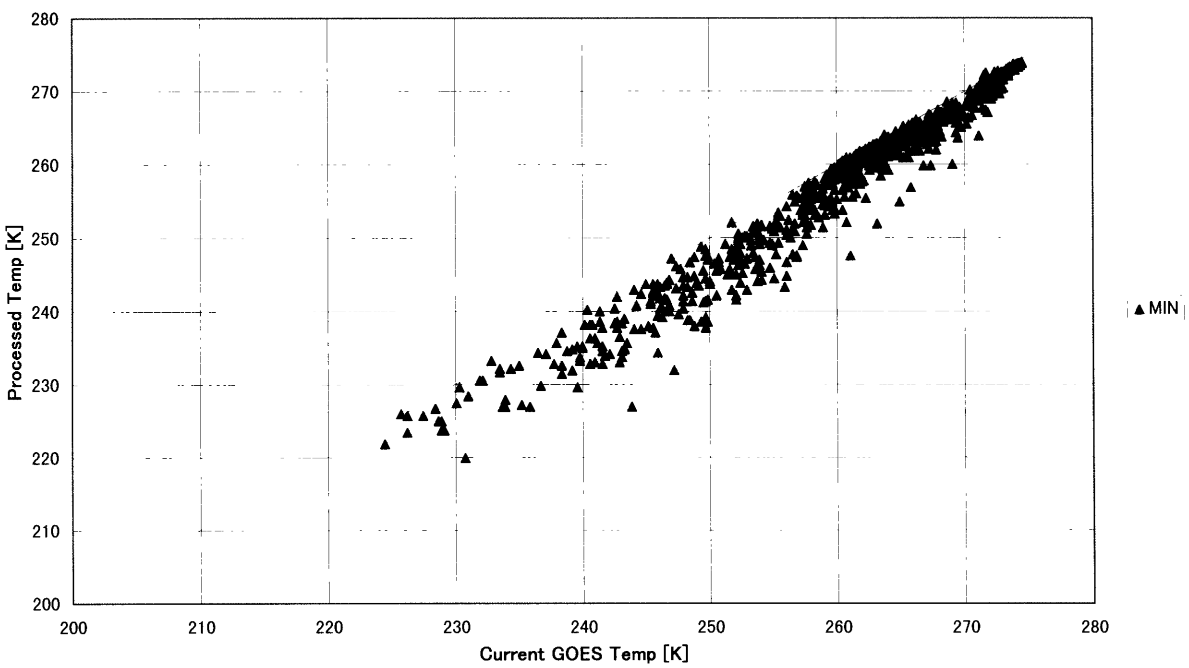
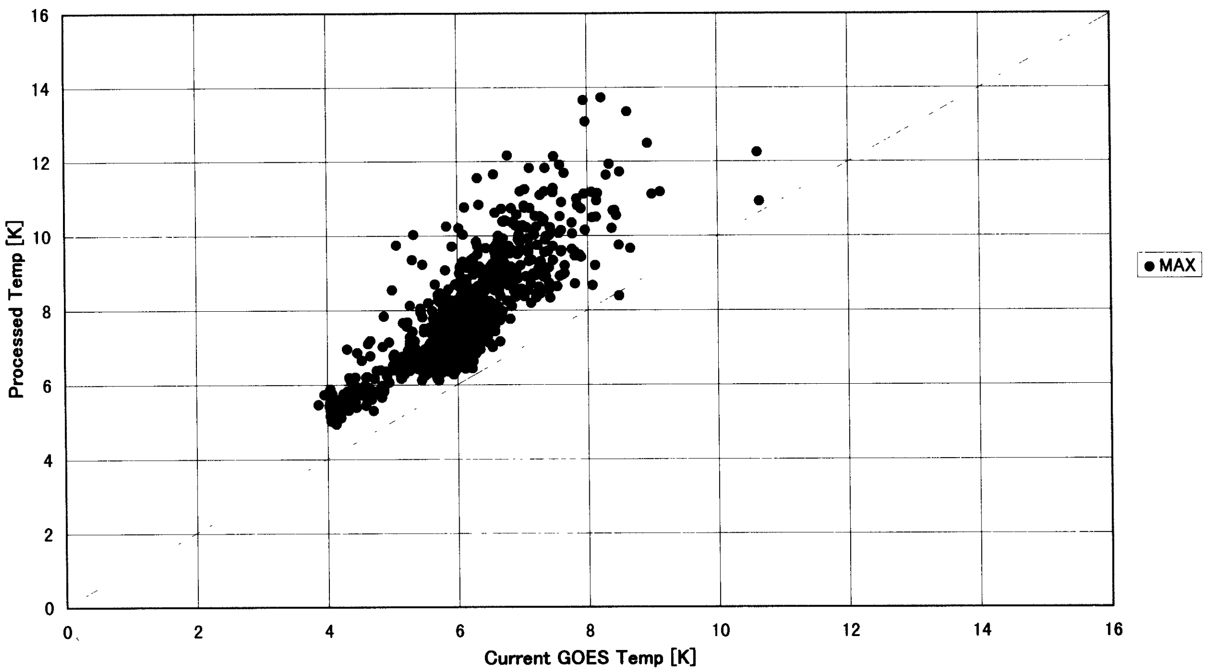


Figure A-10.a Maximum(Top) and Minimum(Bottom) Temperatures of Baja California, Channel 4



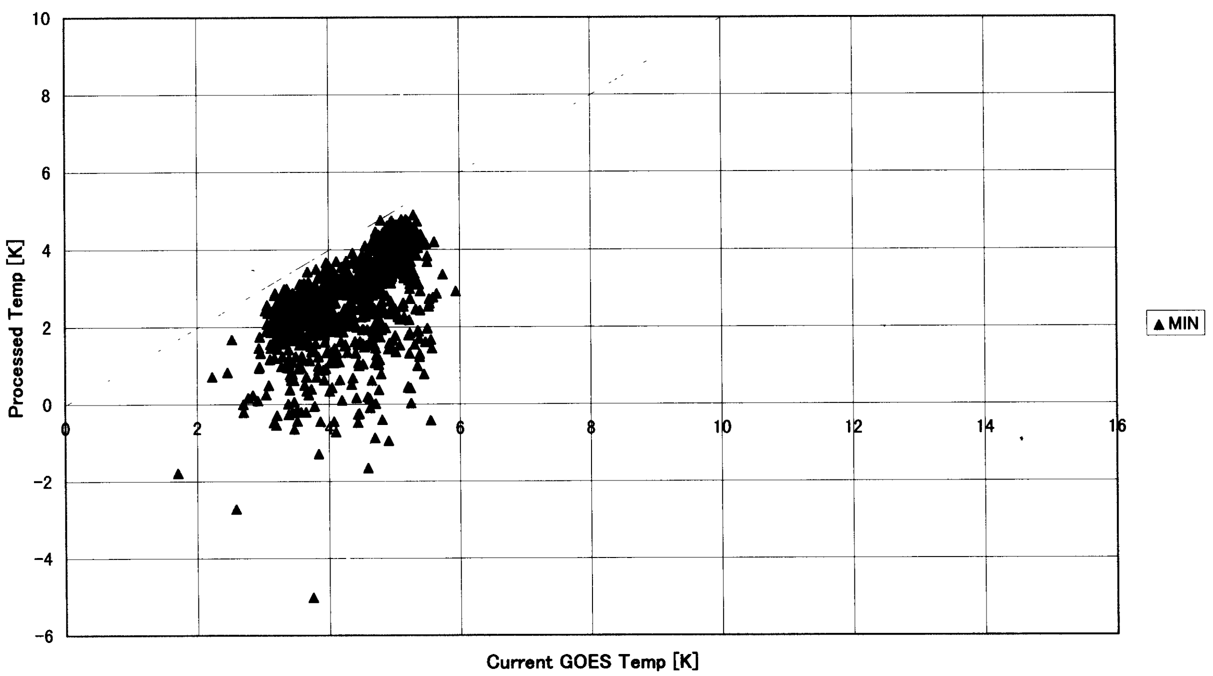
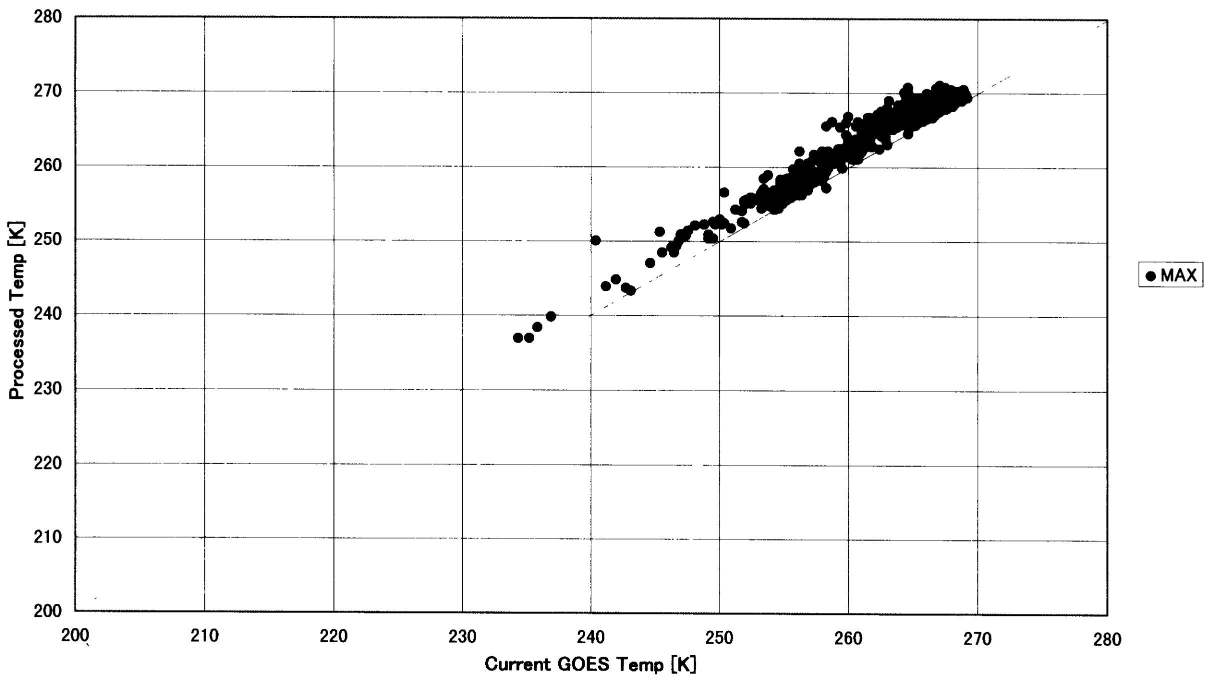


Figure A-10.b　Maximum(Top) and Minimum(Bottom) Temperatures of Baja California, Channels 4-5



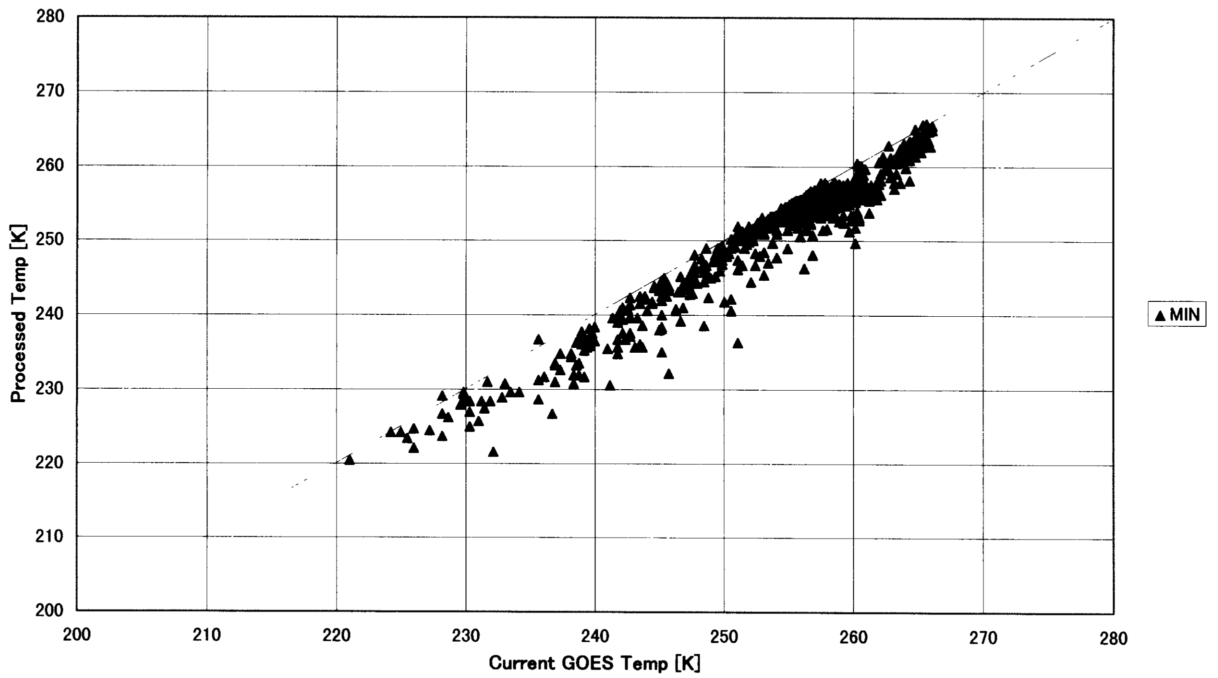
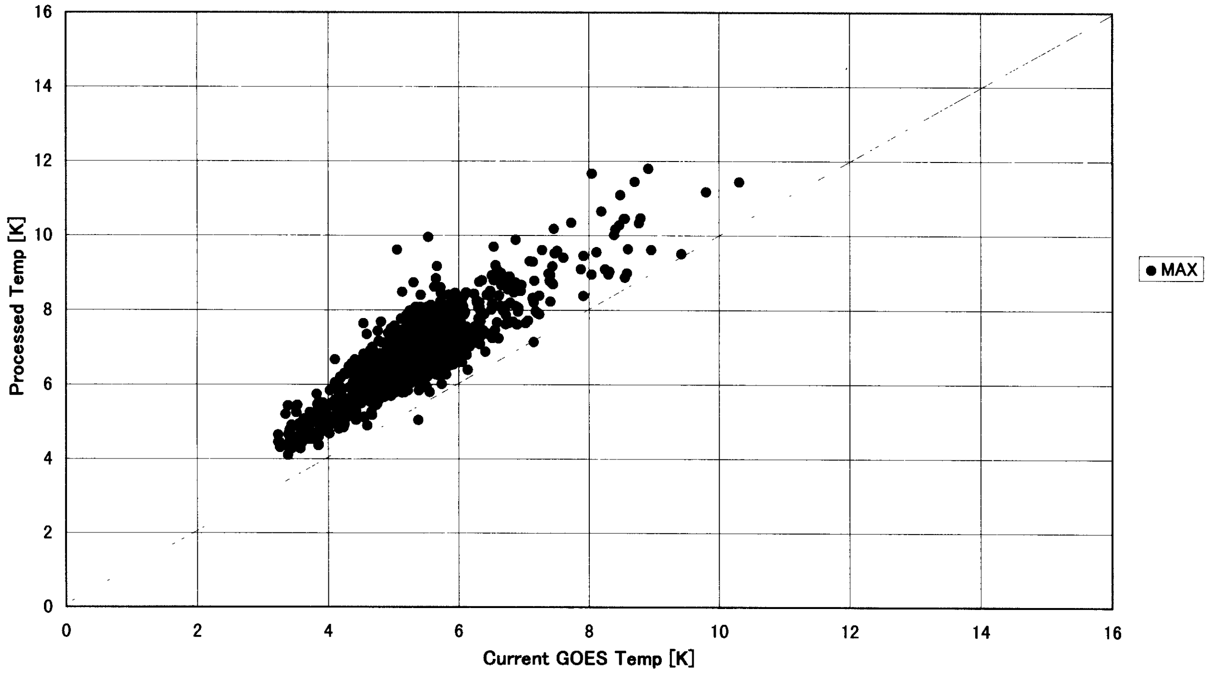


Figure A-11.a Maximum(Top) and Minimum(Bottom) Temperatures of San Francisco Bay, Channel 4



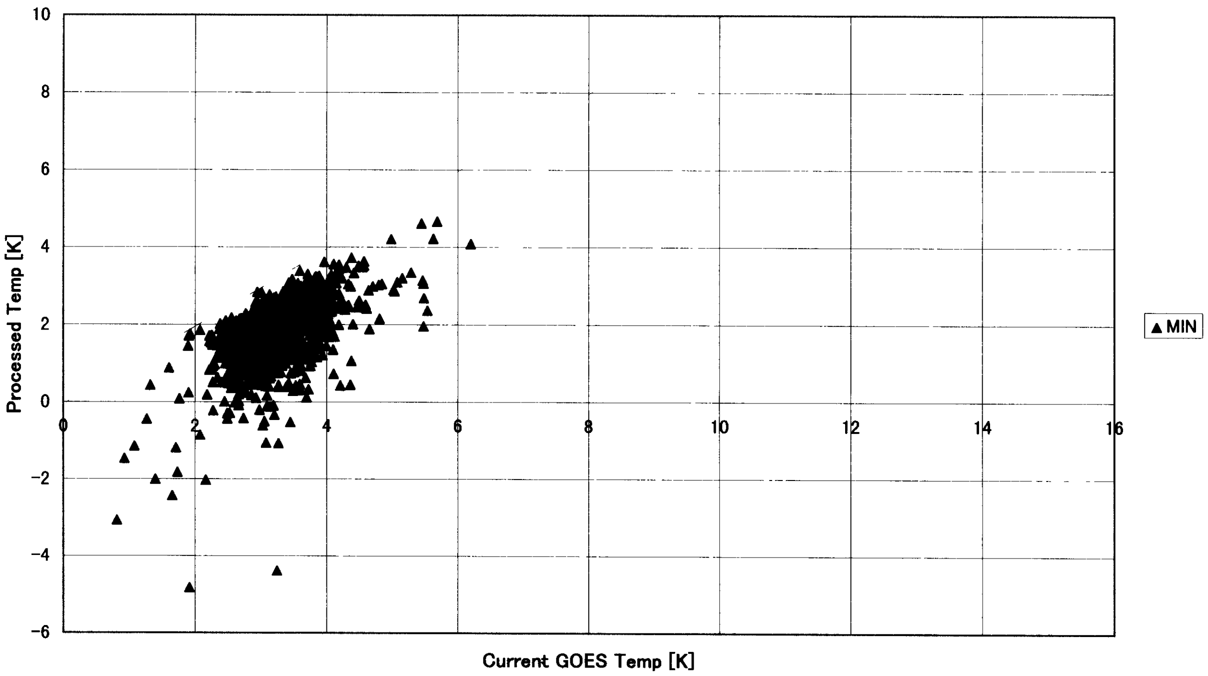


Figure A-11.b Maximum(Top) and Minimum(Bottom) Temperatures of San Francisco Bay, Channels 4-5

Low Pass 1	Low Pass 2	Low Pass 3	Low Pass 4	Low Pass 5	Low Pass 6	Low Pass 7
0.001	-0.002	-0.001	0.002	0.002	-0.001	-0.002
-0.003	0.002	0.004	0.001	-0.003	-0.003	0.002
0.007	0.002	-0.005	-0.006	0	0.006	0.005
-0.011	-0.011	-0.001	0.01	0.012	0.003	-0.008
0.01	0.021	0.017	0.002	-0.014	-0.021	-0.014
0.003	-0.02	-0.033	-0.031	-0.014	0.009	0.029
-0.035	-0.008	0.022	0.045	0.054	0.047	0.025
0.083	0.067	0.039	0.004	-0.031	-0.061	-0.081
-0.136	-0.145	-0.142	-0.128	-0.104	-0.072	-0.034
0.178	0.212	0.242	0.266	0.286	0.302	0.309
0.807	0.764	0.717	0.67	0.627	0.584	0.538
0.178	0.212	0.242	0.266	0.286	0.302	0.309
-0.136	-0.145	-0.142	-0.128	-0.104	-0.072	-0.034
0.083	0.067	0.039	0.004	-0.031	-0.061	-0.081
-0.035	-0.008	0.022	0.045	0.054	0.047	0.025
0.003	-0.02	-0.033	-0.031	-0.014	0.009	0.029
0.01	0.021	0.017	0.002	-0.014	-0.021	-0.014
-0.011	-0.011	-0.001	0.01	0.012	0.003	-0.008
0.007	0.002	-0.005	-0.006	0	0.006	0.005
-0.003	0.002	0.004	0.001	-0.003	-0.003	0.002
0.001	-0.002	-0.001	0.002	0.002	-0.001	-0.002

Table A-5 Low-pass Filter

Florida

	Current GOES (counts)	Processed (counts)
#1	0.68	1.82
#2	0.91	2.20
#3	1.14	2.27
#4	1.25	2.33
#5	1.31	2.85
Average	1.06	2.29

Baja California

	Current GOES (counts)	Processed (counts)
#1	0.36	1.94
#2	0.59	2.23
#3	0.62	1.74
#4	0.64	2.42
#5	0.66	1.91
Average	0.57	2.05

San Francisco Bay

	Current GOES (counts)	Processed (counts)
#1	0.51	1.95
#2	0.54	2.08
#3	0.60	2.44
#4	0.64	1.80
#5	0.64	1.99
Average	0.59	2.05

Table A-6 Standard Deviation of Clear Sky Area

To assess an impact on cloud motion winds, pattern matching using the cross-correlation method was performed for an area of 16 by 16 pixels (processed image) and 8 by 16 pixels (current GOES image) on channel 4. As mentioned above, the acquisition of the over-sampling image was repeated at each geographical location, whose interval was approximately 90 seconds. The pattern matching was performed on the lattice of 16 by 16 pixels on the processed image and 8 by 16 pixels on the current GOES image. The correlation surface of the pattern matching was interpolated and a correlation peak was detected.

The results of the pattern matching are shown from Figure A-14 through A-16 as the cloud motion winds. It is remarkable that the winds which indicate 10 m/s or over have a bias

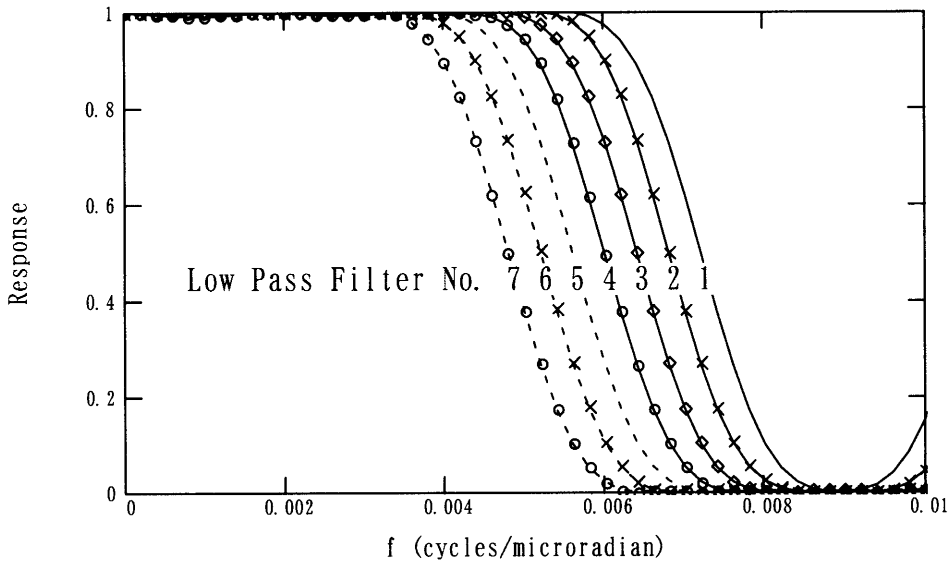


Figure A-12　Low Pass Filter Response

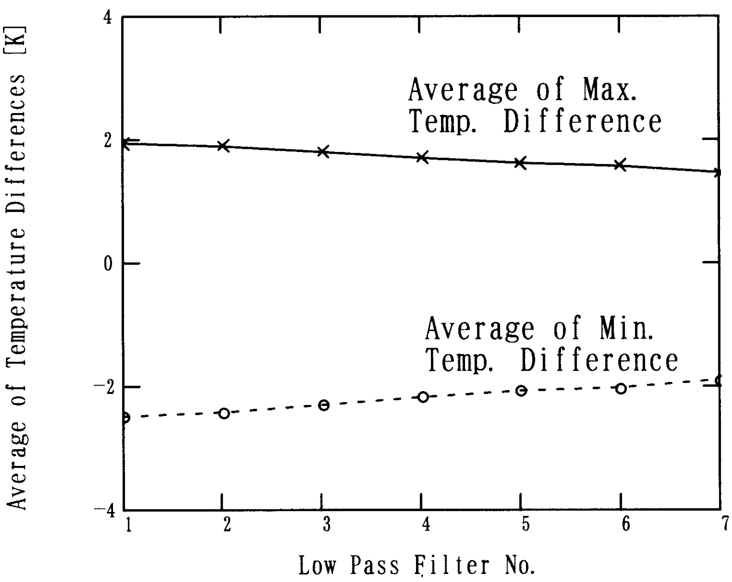
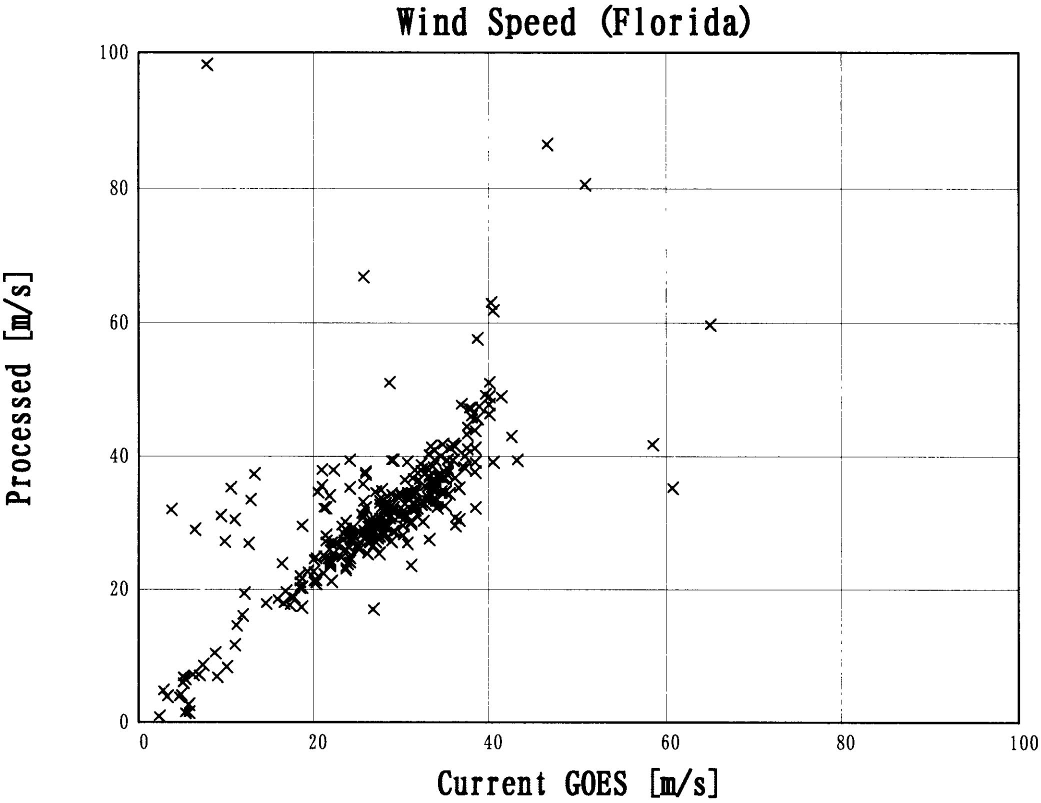


Figure A-13　Low Pass Filter Examination

of 3.9 m/s at Florida, and 4.8 m/s at Baja California. It is reported that the cloud motion winds for upper levels are biased slow (more than 2 m/s) for speed exceeding 30 m/s comparing with aircraft measurements[3]. Although the analysis of the over-sampling image is preliminary, it means the over-sampling image has a potential improvement on the cloud motion winds with the better cloud height assignment described the above.

Reference

1. Baucom, J.G., and Weinreb, M. : 1996, Characteristics of E/W stripes in infrared images from the GOES-10 Imager, SPIE Vol. 2812, pp 587-595, Aug. 7-9, 1996.
2. Bremer, J.C., and Comeyne III, G. J. : 1994, Optimization of the GOES-I Imager's radiometric accuracy: drift and 1/f noise suppression, Optical Engineering Vol. 33, No. 10, pp 3324-3333, Oct. 1994.
3. Thoss, A., 1991: Proceedings. First International Winds Workshop, Washington, D.C., USA, 17-19 September 1991, pp 105-112.



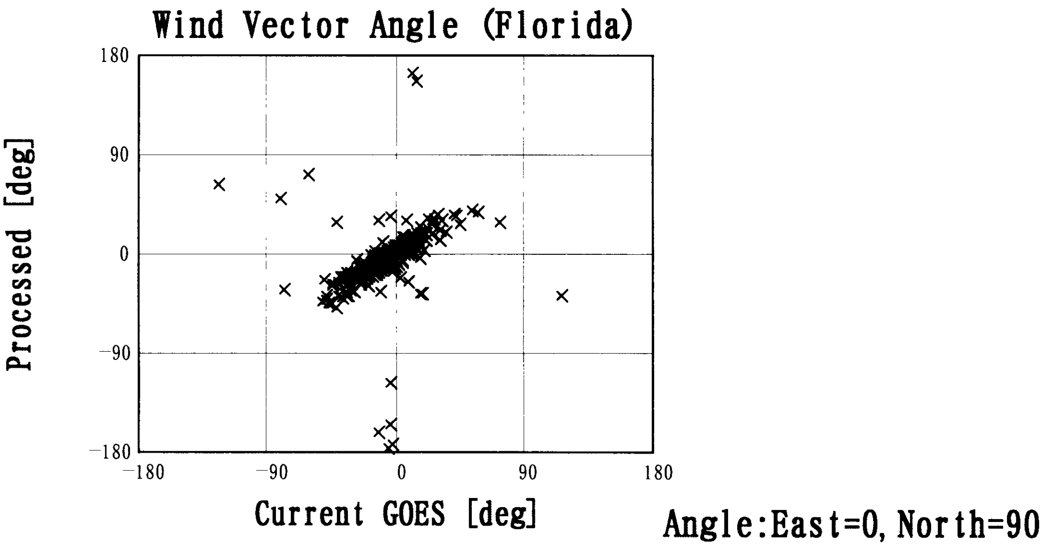
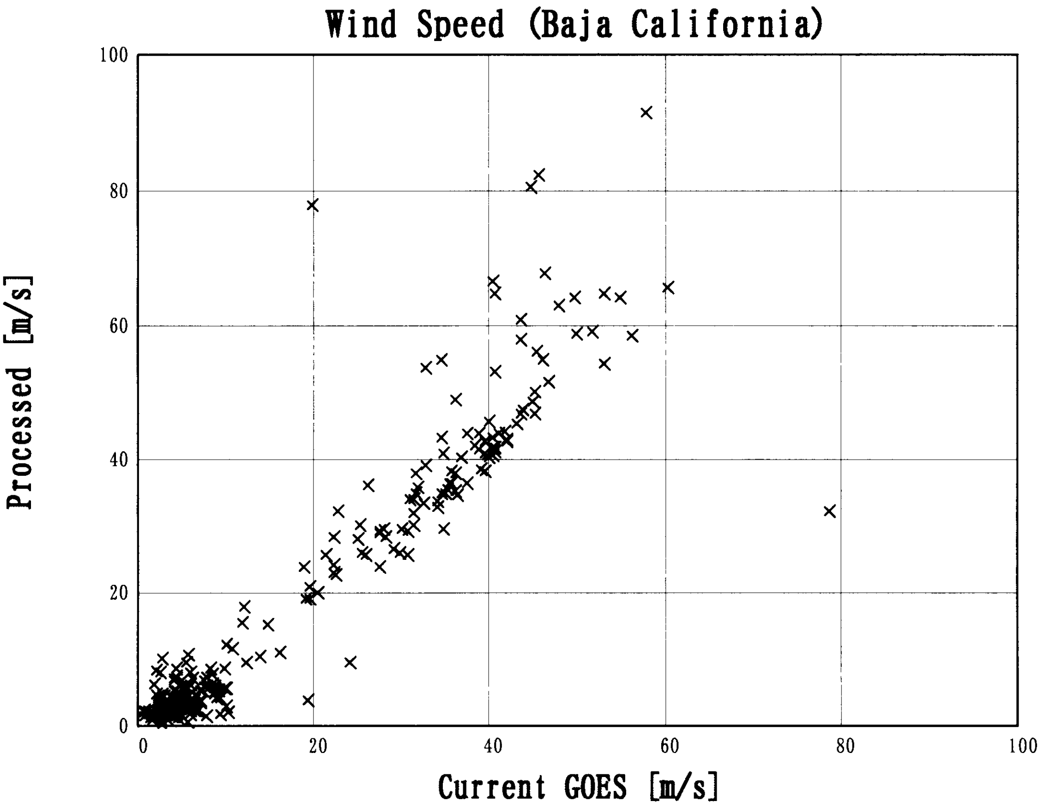


Figure A-14　Cloud Motion Winds of Florida Image on Channel 4
Wind Speed (Top) and Direction (Bottom)



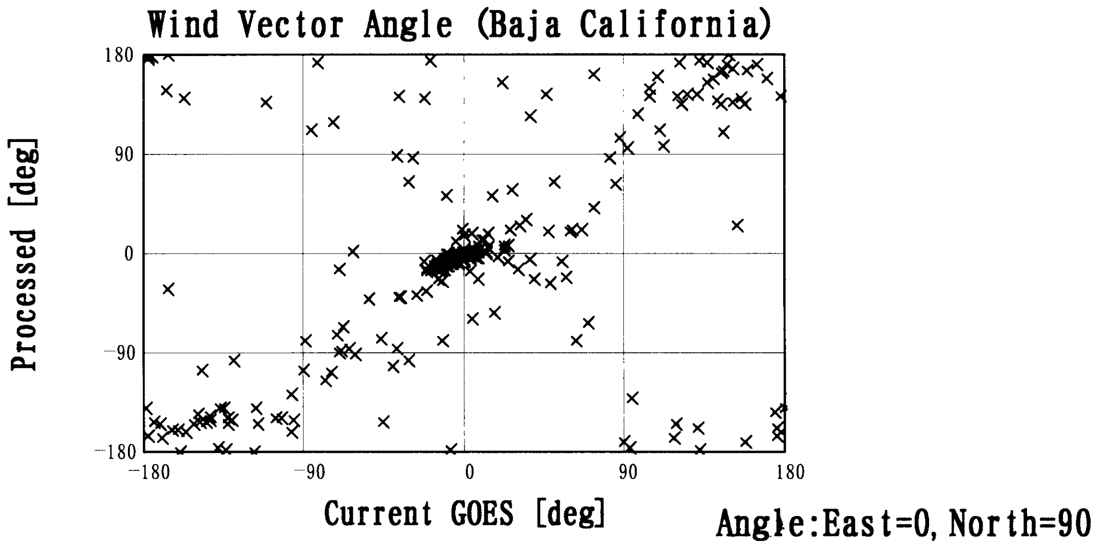
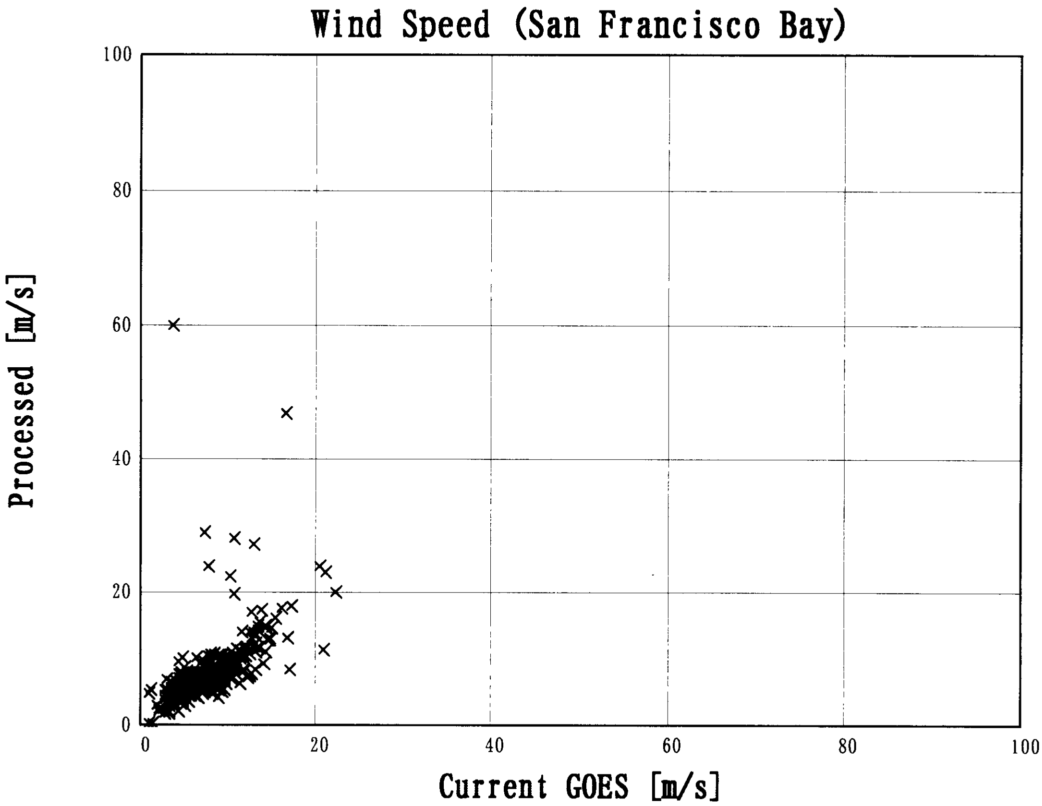


Figure A-15 Cloud Motion Winds of Baja California Image on Channel 4
Wind Speed (Top) and Direction (Bottom)



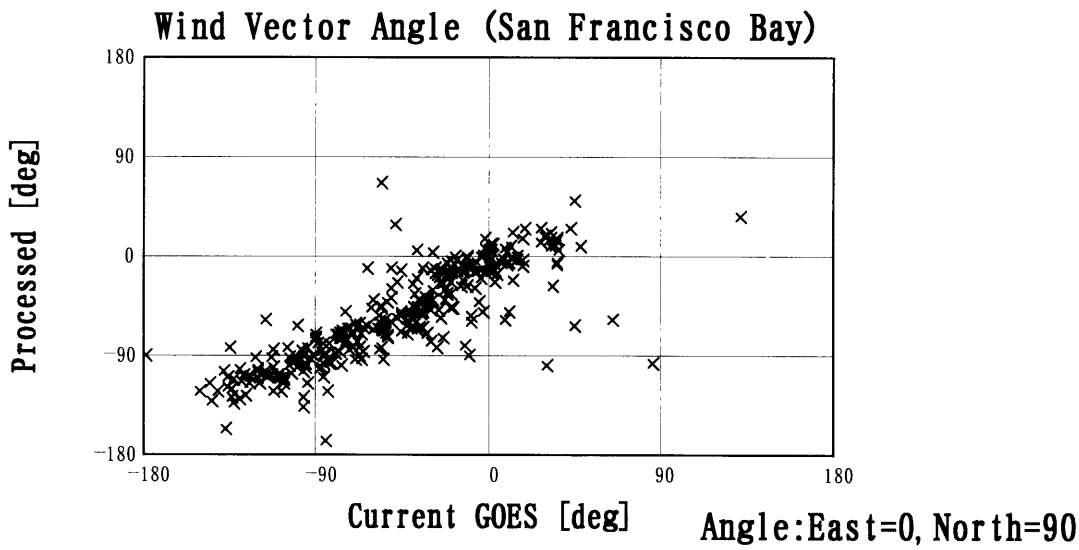


Figure A-16　Cloud Motion Winds of San Francisco Bay Image on Channel 4
Wind Speed (Top) and Direction (Bottom)

Appendix B

AVHRR An abbreviation for Advanced Very High Resolution Radiometer. It is one of payloads on TIROS-N / NOAA series.

IFOV An abbreviation for Instantaneous Field of View. It defines the angular response function of the radiance that is captured instantaneously by Imager's visible and infrared detectors. Input scene intensity as a function of angle is convoluted with IFOV.

Imager A visible and infrared scanning radiometer on MTSAT.

MTF An abbreviation for Modulation Transfer Function. It defines imaging gain as a function of spatial frequency. MTF is derived by taking the Fourier transform of IFOV or PSF. It shows a measure of an instrument's ability to detect contrast changes on observed scenes. High MTF means high contrast on an output image.

Nyquist frequency A half of sampling frequency. The Nyquist frequency is given by:

$$\text{Nyquist frequency} = 1/(2 \times \text{spatial sampling interval})$$

PSF An abbreviation for Point Spread Function. It defines a radiance angular response function when the Imager observes a point light source.