GOES-16 and GOES-17 ABI INR Assessment

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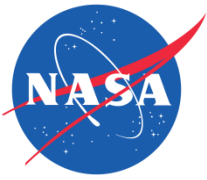4. Chesapeake Aerospace, LLC, Annapolis, MD

SPIE
08/13/2019

Overview

- Background – GOES-16 and GOES-17 Advanced Baseline Imager (ABI)

- Algorithm accuracy assessment of Image navigation and registration (INR) Performance Assessment Tool Set (IPATS)

- The development of the view zenith angle (VZA) filter

- Long-term navigation (NAV) trend of GOES-16 and GOES-17 ABIs

- Summary

ABI Image Characteristics

Spectral	• 16 channels, 0.47 µm to 13.3 µm
Spatial Resolution	• Fixed Grid (FG) coordinate system with sample spacing of 14, 28, or 56 µrad (0.5, 1, or 2 km at nadir)
Coverage	• Full Disk (FD): 17.4 deg diameter centered at nadir • CONUS: Rectangular, 5000 km EW x 3000 km NS • Mesoscale: Rectangular, 1000 km EW x 1000 km NS
Temporal	• FD: 5 to 10 min; CONUS: 5 min; Mesoscale: 30 sec

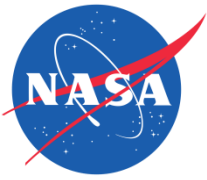| Satellite	Launch Date	Provisional Date of ABI L1B products	Start date of operational
GOES-16	11/19/2016	06/01/2017	12/18/2017
GOES-17	03/01/2018	11/28/2018	02/12/2019

INR Performance Assessment Tool Set (IPATS)

The IPATS was designed and developed to generate INR performance metrics:

- Navigation (NAV) error: Difference between location of pixel in data product and true location.

- Channel-to-channel registration (CCR) error: Relative navigation error of corresponding pixels of different channels in the same frame.

- Frame-to-frame registration (FFR) error: Relative navigation error of corresponding pixels of same channel in consecutive images.

- Within-frame registration (WIFR) error: Difference between radial separation of two pixels on the fixed grid coordinate system and their true angular separation. WIFR is calculated indirectly from the NAV results.

- Swath-to-swath registration (SSR) error: Relative navigation error of two neighboring pixels on opposite sides of the horizontal image swath boundary.

This talk focuses on the NAV metric.

IPATS Algorithm Accuracy Assessment

$$\epsilon_{INR} = \epsilon_{INR-intrinsic} + \epsilon_{ME}$$

ϵ_{INR} IPATS measured INR error.

$\epsilon_{INR-intrinsic}$ the INR-intrinsic error of the ABI system.

ϵ_{ME} the measurement error due to uncertainty in the IPATS algorithms.

An error source of ϵ_{ME} is the **stair-step error** which occurs in registering two images of different spatial resolutions. To evaluate ϵ_{ME} quantitatively, GOES images with the known shifts were processed through IPATS. The IPATS assessments results were then compared with the known shifts.

Generation of the Known Shifts Data

Generate GOES
Resolution sub-
images with
induced shift

The size of the grid cell is
same as the size of GOES
pixel.
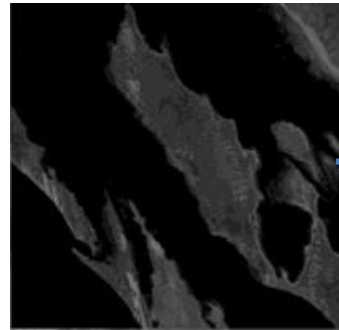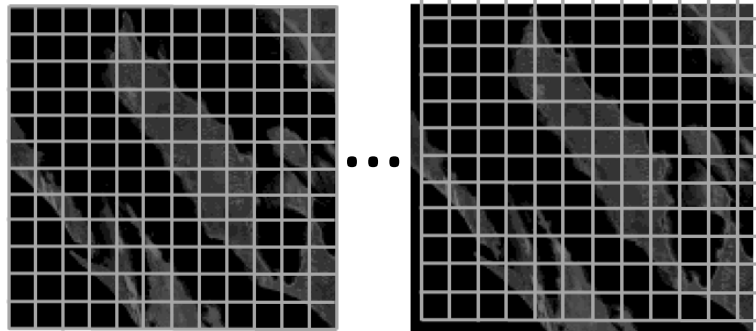
Landsat
Images
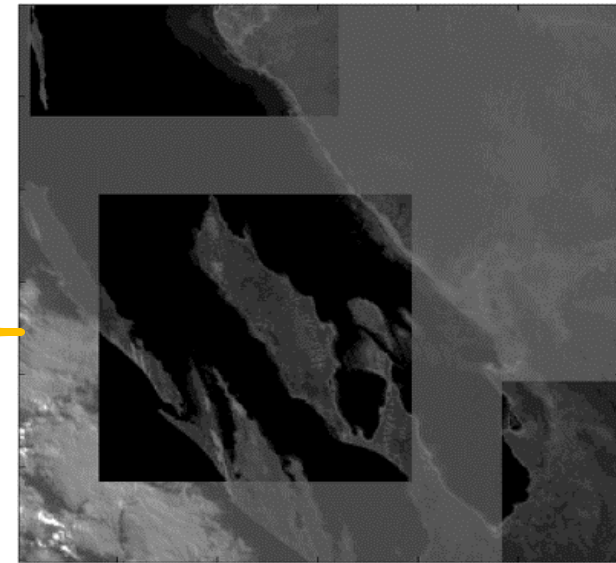
GOES Resolution images
with embedded sub-
images which contain
the induced shift.
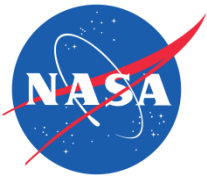
GOES Resolution images
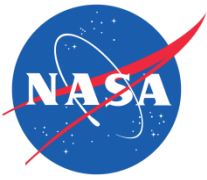
Sub Pixel Factor (SPF)

IPATS Configuration

- Image registration: Normalized Cross Correlation.

- Up-sample method: Bi-cubic interpolation.

- Edge enhancement: Sobel.

- Number of chips: 136.

At which resolution the images should be compared?

- GOES? Landsat? Or a resolution in between?
- For convenience, we introduce the term 'sub-pixel factor' (SPF) to indicate the degree of up-sampling applied to ABI images. For instance, an SPF of 2 means that the ABI images are up-sampled to half an ABI pixel before matching occurs.
- Grycewicz et al. found that stair-step error magnitude and frequency are impacted by SPF value.

Thomas J. Grycewicz, Bin Tan, Peter J. Isaacson, Frank J. De Luccia, John Dellomo, "Avoiding stair-step artifacts in image registration for GOES-R navigation and registration assessment," Proc. SPIE 9972, Earth Observing Systems XXI, 99720T (19 September 2016); doi: 10.1117/12.2238640
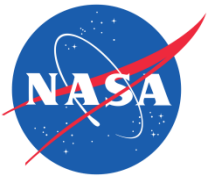
RMSE of Measured Misregistration
SPF =1

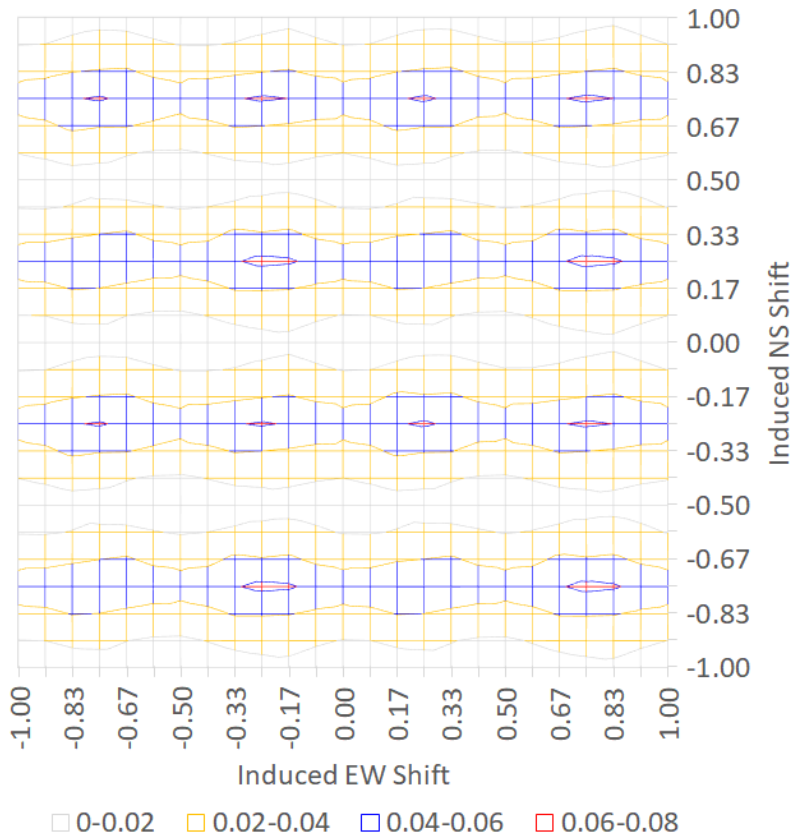

Red line marked where the largest RMSE happens.

The intrinsic error in one direction leads to measurement error in both directions. There are measurement error in both EW and NS directions when intrinsic error at one direction is 0.
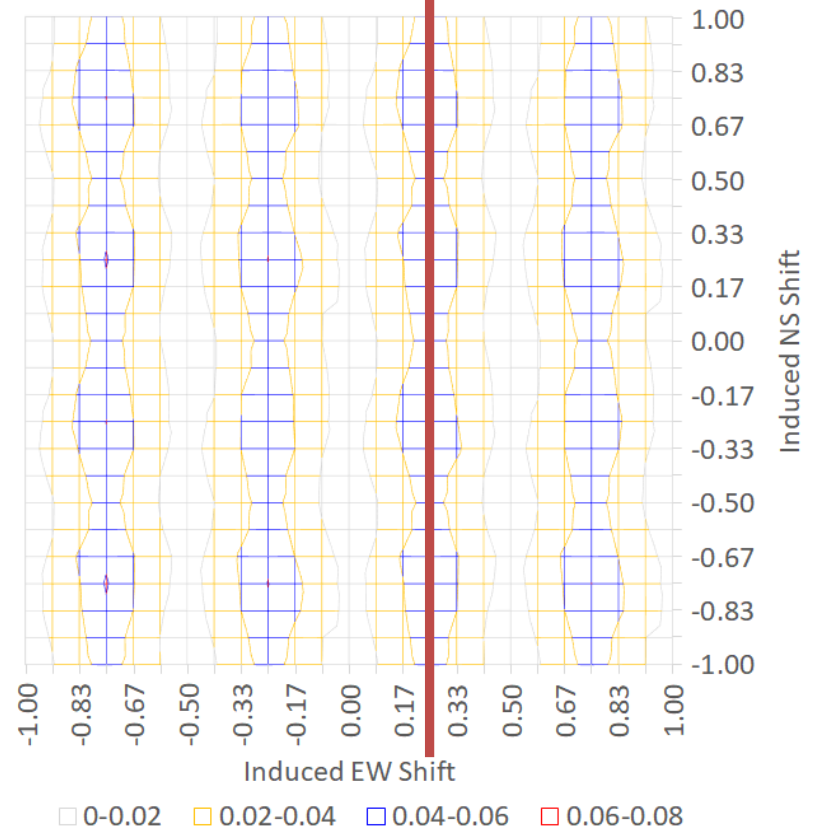
RMSE of Measured Misregistration
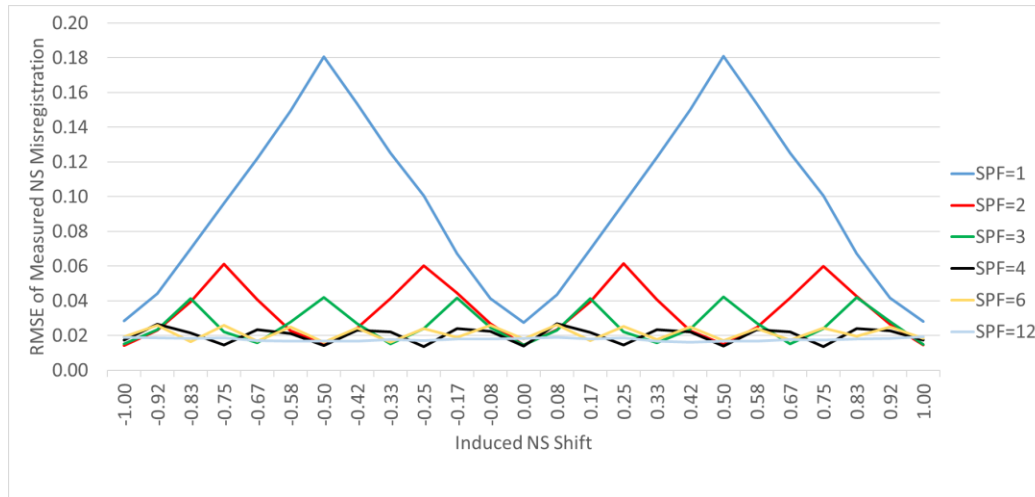## SPF =2

RMSE of Measured EW Misregistration (SPF = 2)
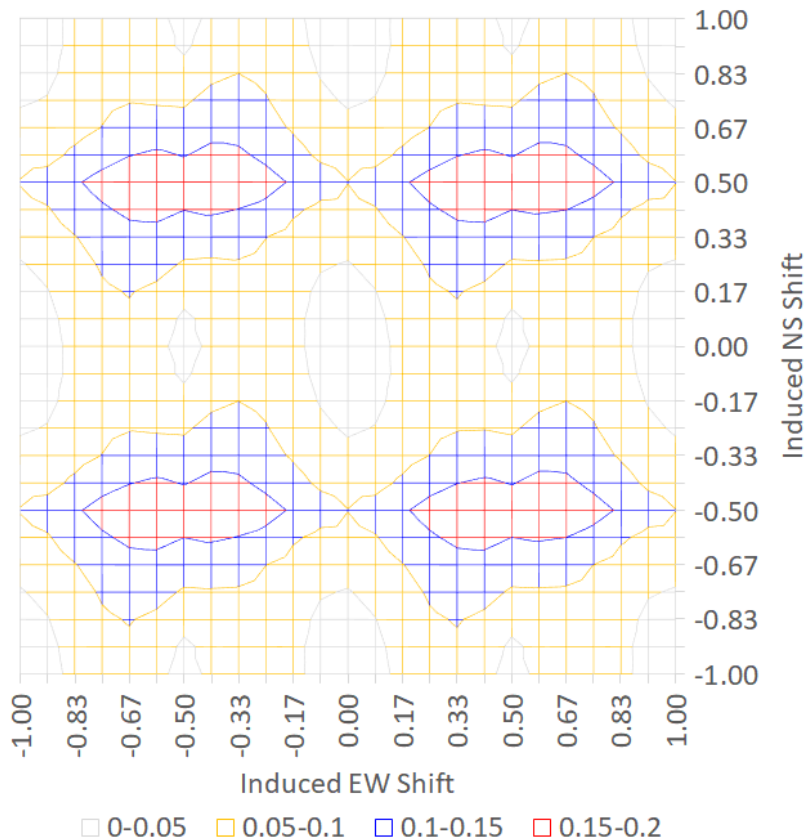
RMSE of Measured NS Misregistration (SPF = 2)

Red line marked where the largest RMSE happens.

Summary of SPF Effect

❖ Upper panel is the measured NS misregistration vs the induced NS shift at the largest RMSE line marked in previous slides.

❖ The lower panel is the peak RMSE values on upper plots.

- The cycle of the stair-step error equals to 1/SPF.

- The amplitude of the stair-step error decreases with increasing SPF.

- RMSE of SPF = 1 is significantly larger than RMSE of other SPFs.

- The RMSE value drops from about 0.06 to 0.02 pixels when SPF increases from 2 to 12.

- The computation time of image matching algorithm has O (SPF^2) time complexity.

- SPF = 2 is the final selection. ϵ_{ME} is within 0.06 pixels.
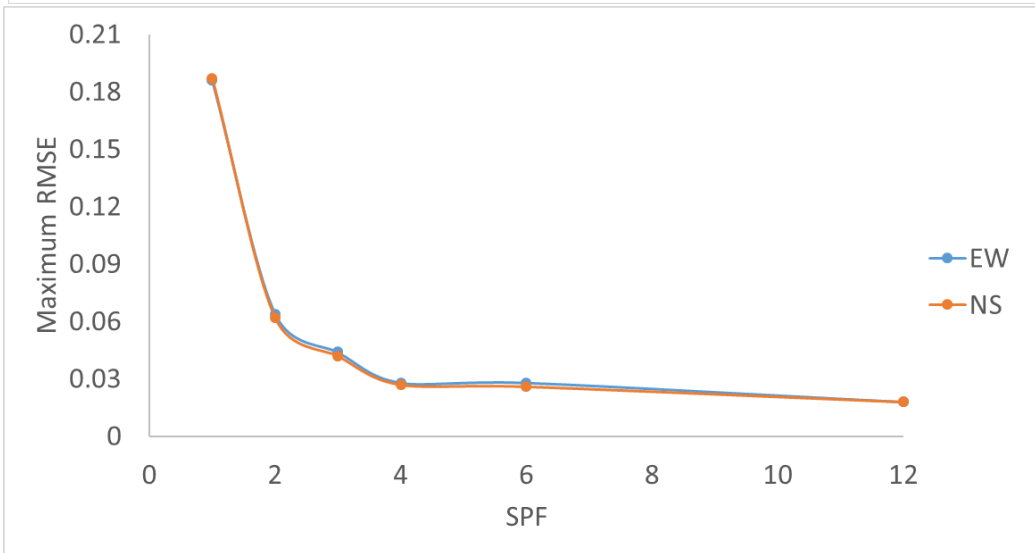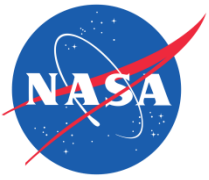
Screening of Raw IPATS Measurements

The accuracy of the IPATS measurements depends the characteristics of the image pair, such as cloud coverage, seasonality, and image observation time. Low quality measurements are removed by:

1. Sun Zenith Angle filter (SZA). (For visible and near-infrared channels only)

2. Analytical Measurement Uncertainty filter (aMU2).

3. Statistic-based filters

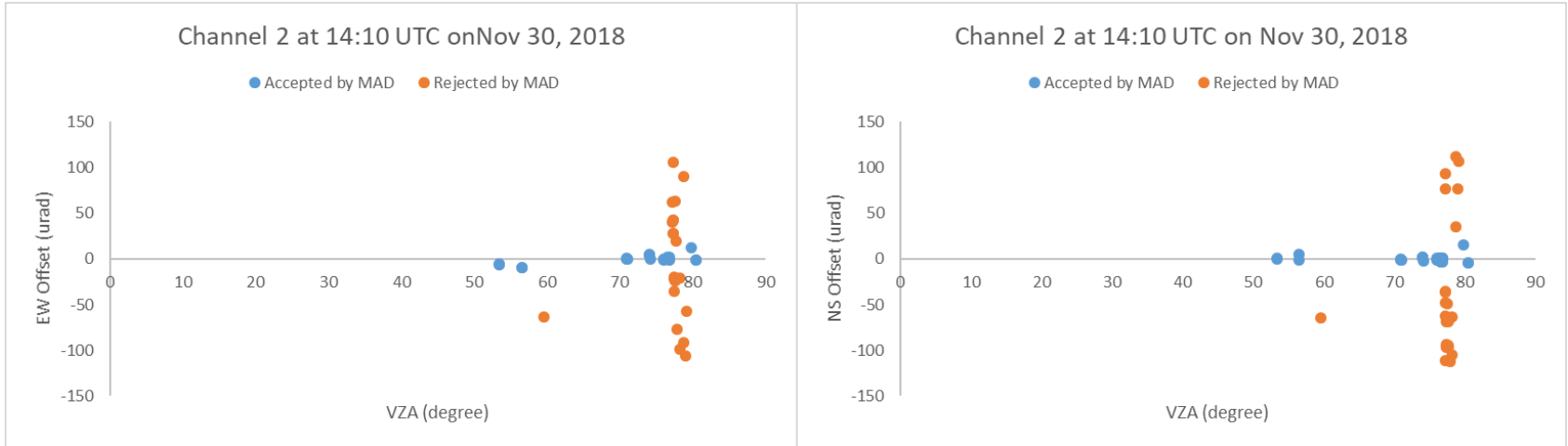   •   Median Absolute Deviation from the median (MAD).

    •   Short Term AbNormal Detection (STAND).
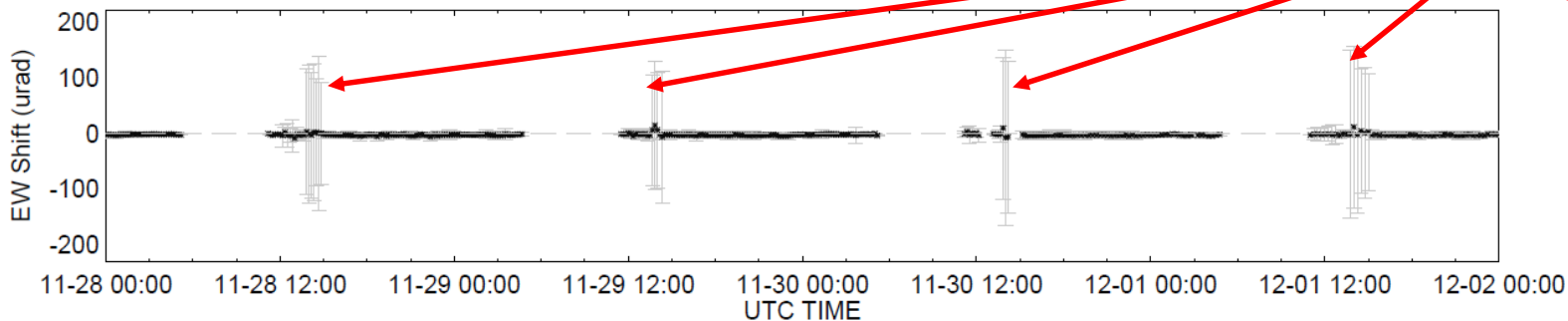
GOES-17 Abnormal Scenes?

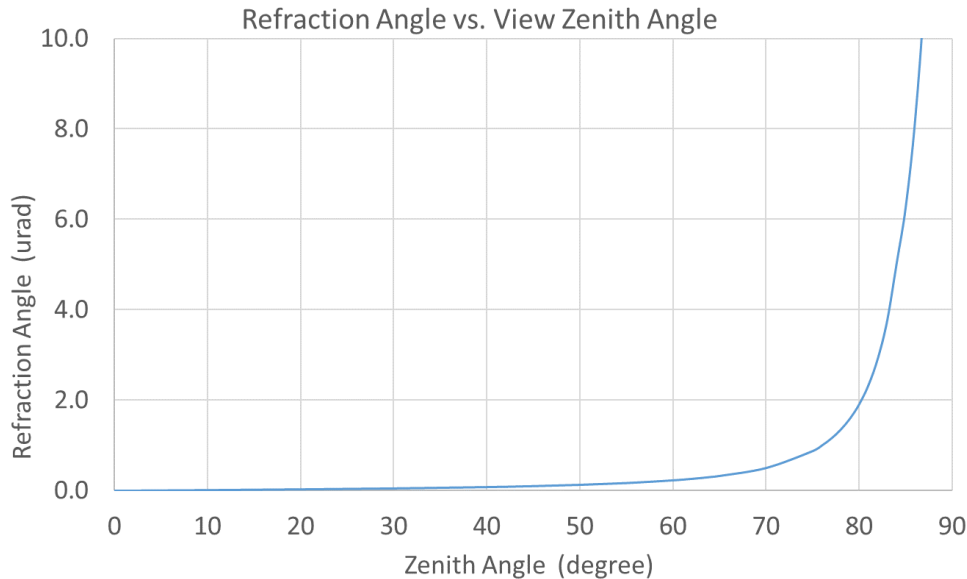# Misregistration against VZA

Sample of abnormal Scene

Channel 2 at 14:10 UTC onNov 30, 2018

● Accepted by MAD ● Rejected by MAD

EW Offset (urad) vs VZA (degree)

Channel 2 at 14:10 UTC on Nov 30, 2018

● Accepted by MAD ● Rejected by MAD

NS Offset (urad) vs VZA (degree)

Sample of normal Scene

Channel 2 at 15:30 UTC on Nov 30, 2018

● Accepted by MAD ● Rejected by MAD

EW Offset (urad) vs VZA (degree)

Channel 2 at 15:30 UTC on Nov 30, 2018

● Accepted by MAD ● Rejected by MAD

NS Offset (urad) vs VZA (degree)

Refraction Effect

Refraction Angle vs. View Zenith Angle

Linear Displacement vs. View Zenith Angle

- The refraction angle and the linear displacement is 0.9 urad and 136 m respectively when VZA equals to 75.

- Comparing to the variation of measured NAV misregistrations, the effect of refraction is marginal.

Noerdlinger, P. D., "Atmospheric refraction effects in Earth remote sensing", ISPRS Journal of Photogrammetry & Remote Sensing vol 54, pp. 360–373 (1998).
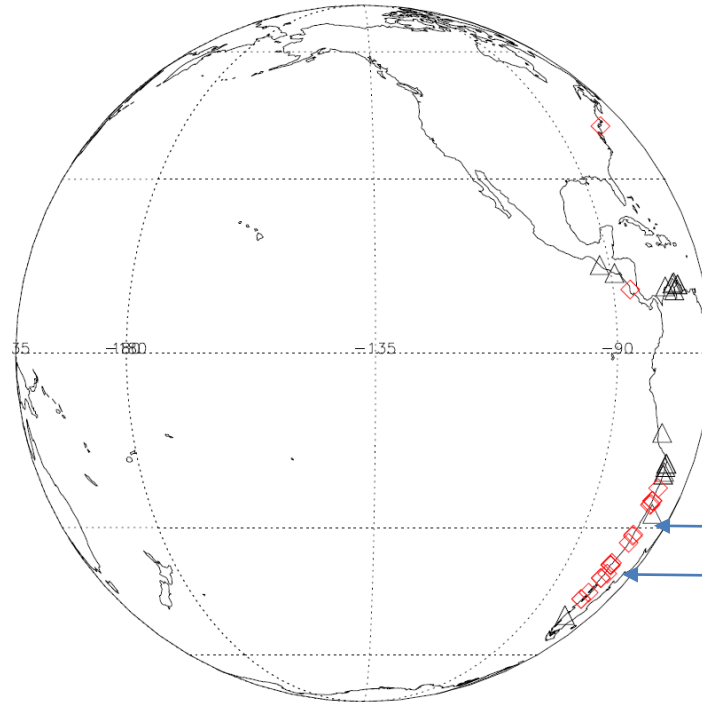
13

Sample Abnormal Scene
(14:10 UTC, Nov 30, 2018)

Channel 2
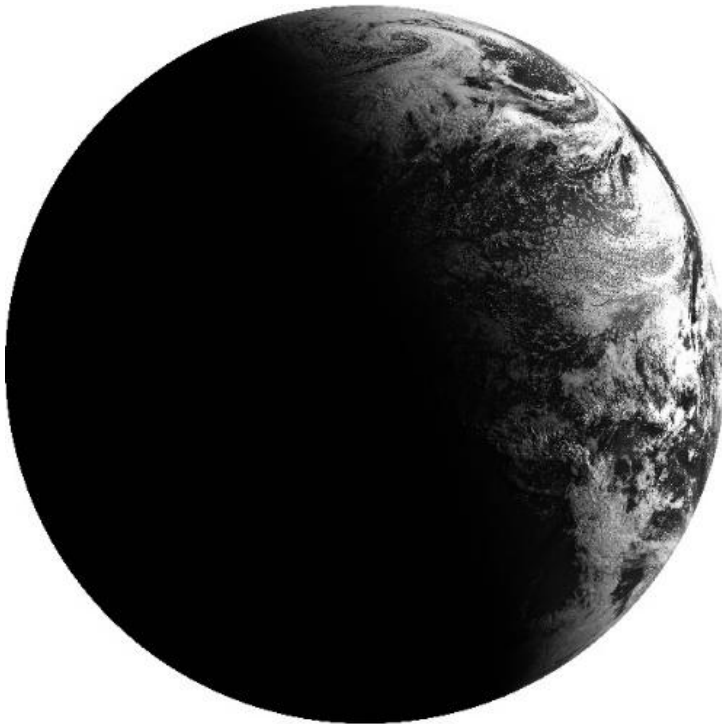
Chip Locations

Black Triangle: chips are accepted by the MAD filter.

Red Diamond: chips are rejected by the MAD filter.

PGD

GDA

CHIP_NAME	EW Offset (urad)	NS offset (urad)	Longitude (degree)	Latitude (degree)	MU_EW	MU_NS
GDA	-22.01	-97.11	-73.45	-37.44	1.12	1.40
PGD	27.38	-110.88	-70.63	-25.57	1.21	2.41

Chips Rejected by the MAD Filter

GDA

PGD

← Landsat Chips

← Resampled Landsat chips and corresponding GOES-17 subset (SPF = 2).
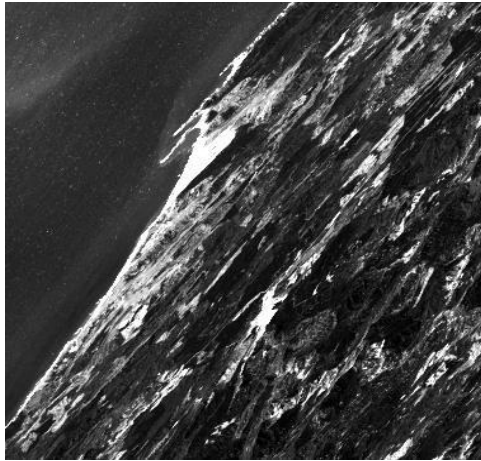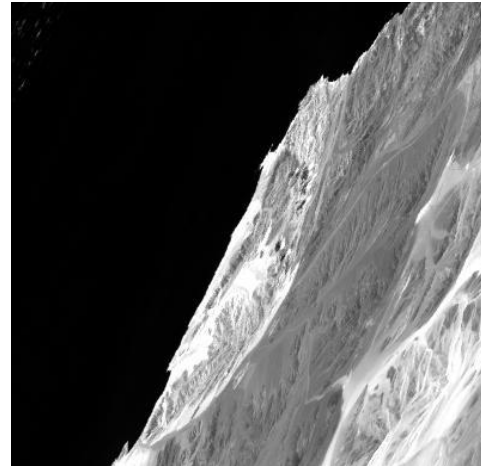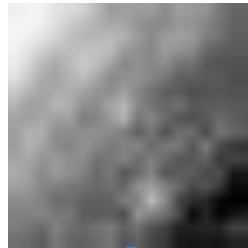
10 X 10 ABI Pixels

14 X 15 ABI Pixels

- The spatial resolution of resampled Landsat chips is about 4 km.
- The detailed spatial features in the original Landsat chips turn into features in a few pixels after the aggregation.
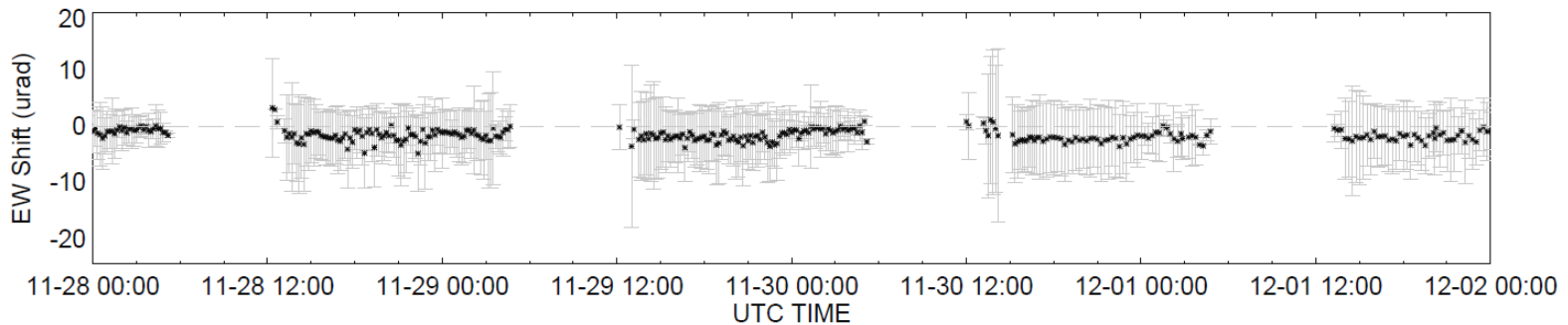- The image registration algorithm does not function well on small images.
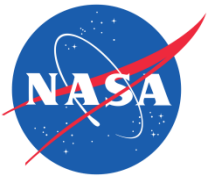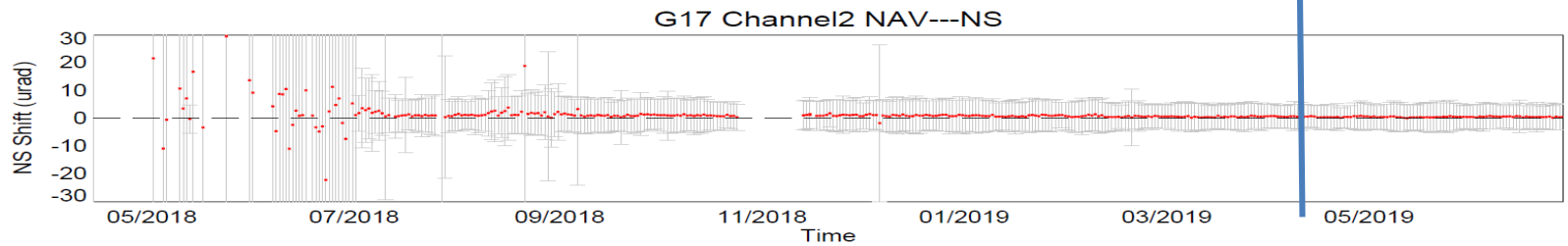
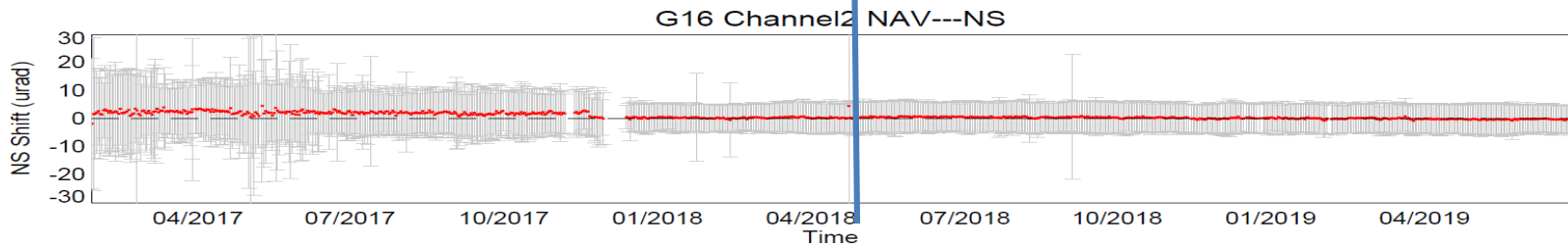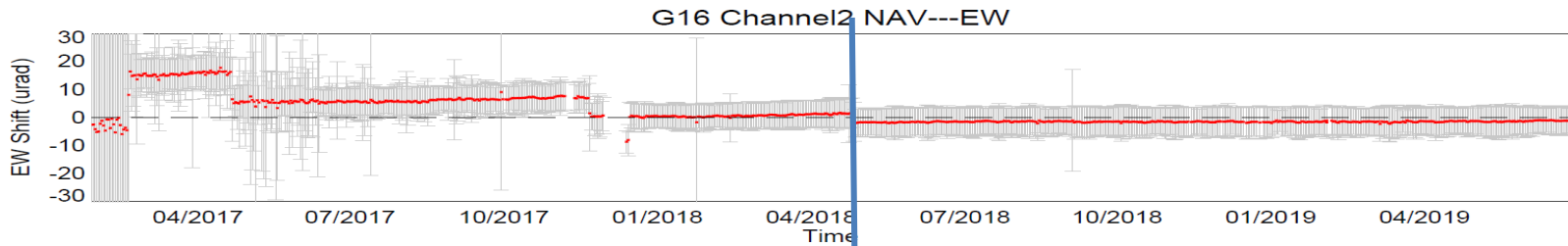# The Effect of the VZA Filter

W/O VZA filter
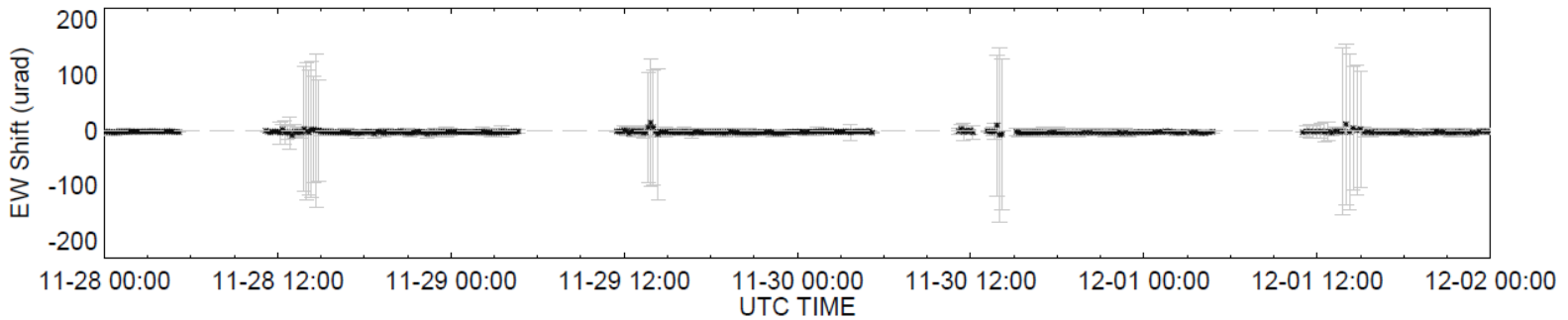
VZA filter at 75 degrees

The VZA filter effectively removed the chips with abnormal assessment results.
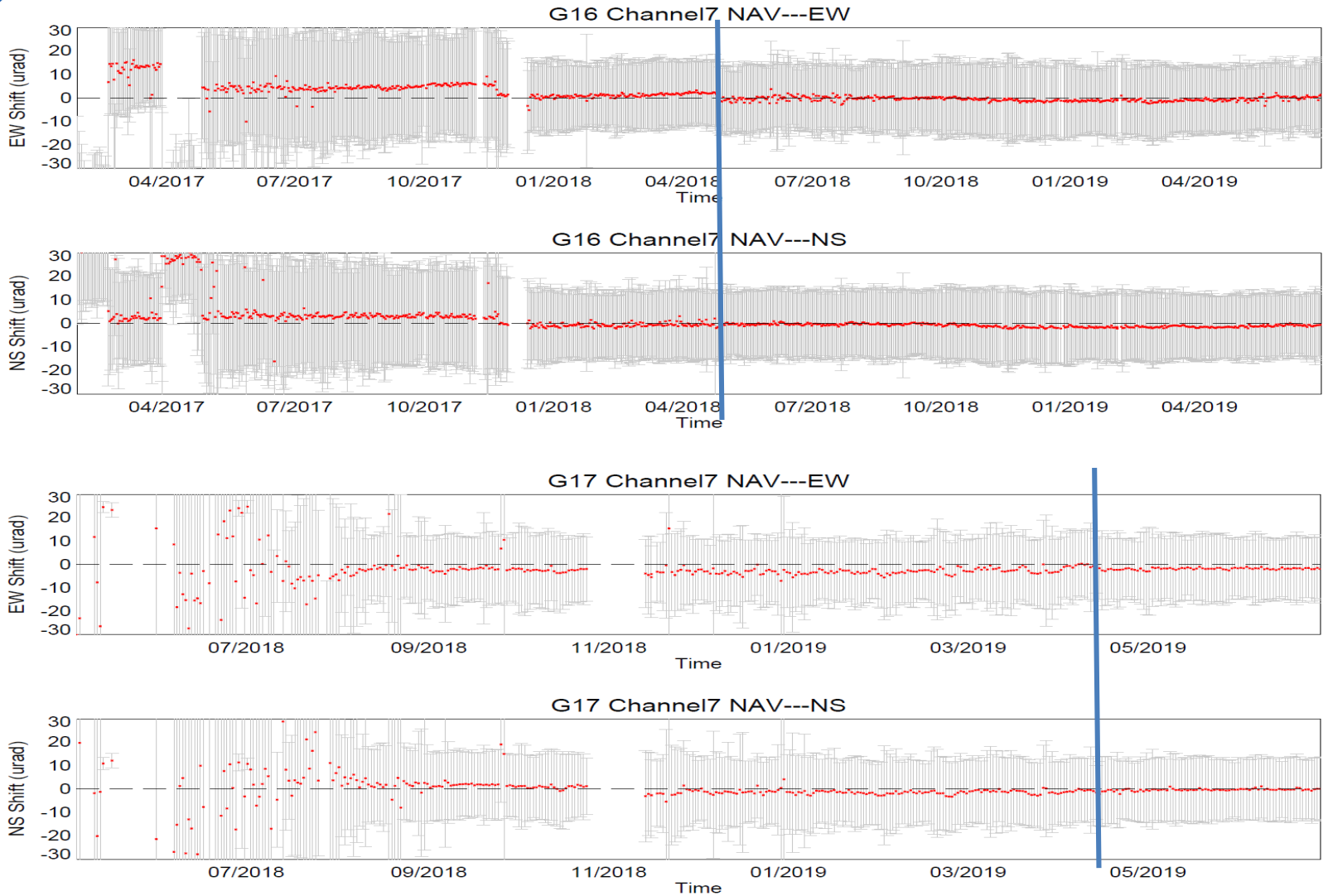
NAV Trend – Channel 2
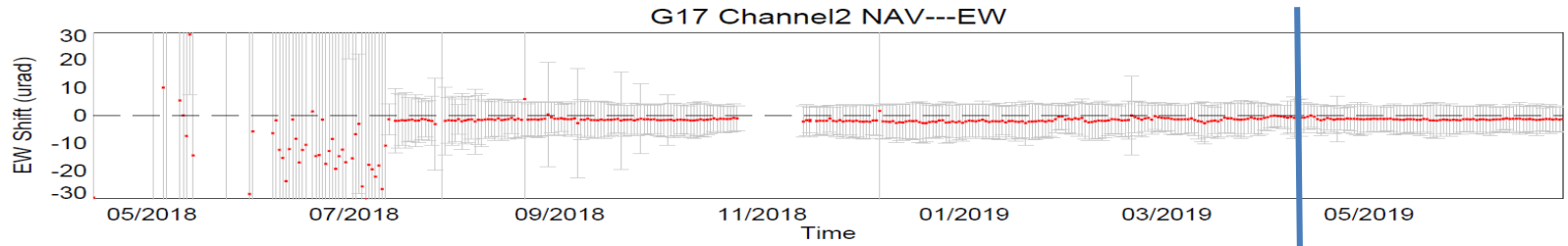
GOES-16
- Feb 2017 – Jun 2019
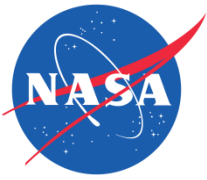- Latest significant improvement in April 2018

GOES-17
- Mar 2018 – Jun 2019
- Latest significant improvement in April 2019
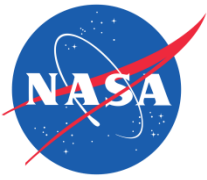
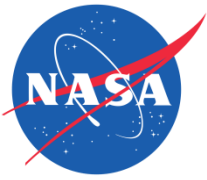# NAV Trend – Channel 7
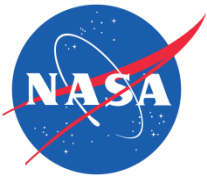

Same timeline as Channel 2.

Summary

- The IPATS measurement accuracy, within 0.06 pixels, is sufficient for INR assessment.

- IPATS is not a static system. Additional filters and/or sub-procedures were developed when the demand emerged, e.g. the development of STAND and VZA filters in post-launch test (PLT) of GOES-16 and GOES-17 respectively.

- NAV INR accuracy improved with updates and tuning in PLT. Currently, NAV errors are about 1-2 urad for all assessed channels of both ABIs.

- IPATS NAV assessments will continue to provide feedback for tuning the navigation algorithms and parameters in future updates and future GOES-R series ABIs.
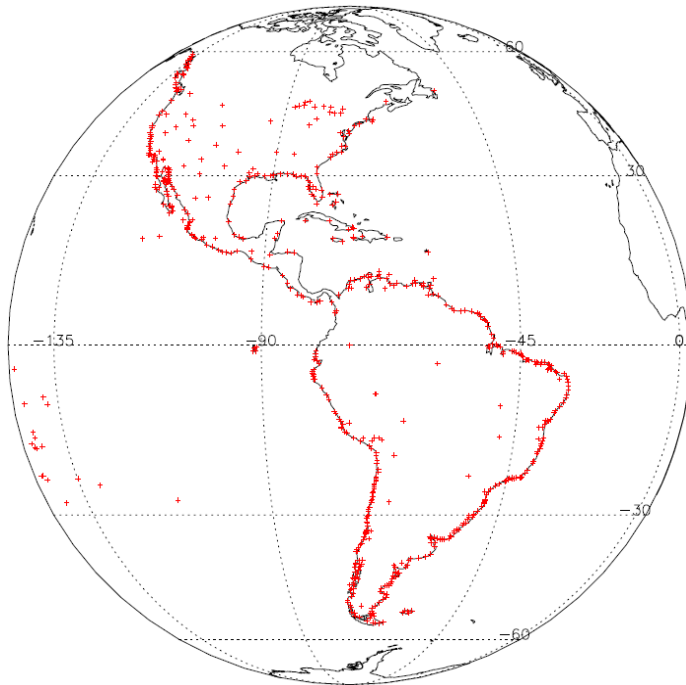
Question?

Backup

The RMSE of measured misregiatration when there is no induced shift

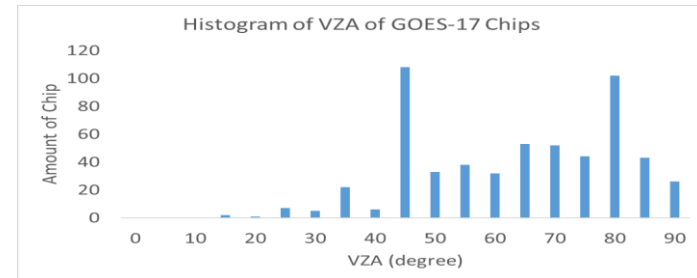| SPF	RMSE (EW)	RMSE (NS)
1	0.005	0.004
2	0.010	0.012
3	0.013	0.014
4	0.013	0.015
6	0.017	0.018
12	0.017	0.018

Unit: Pixel

Landsat Chip Locations

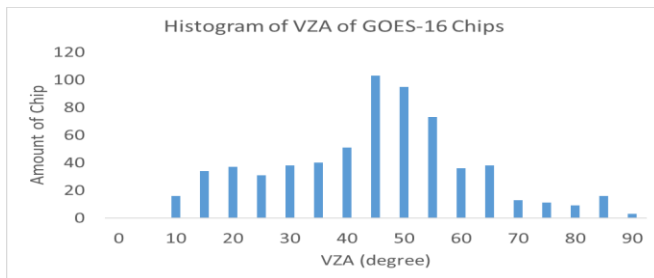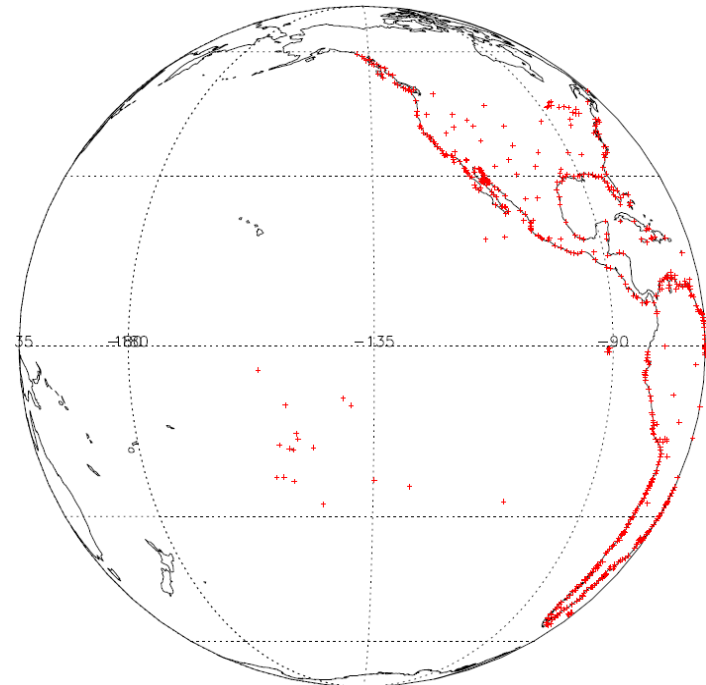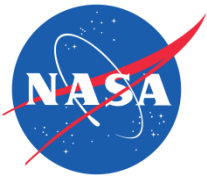## View of GOES-16
(644 locations)

View of GOES-17
(576 locations)

NAV Trend – Channel 13