JPSS-1 VIIRS DNB, Prelaunch Tests & Performance

Steve Mills
Stellar Solutions
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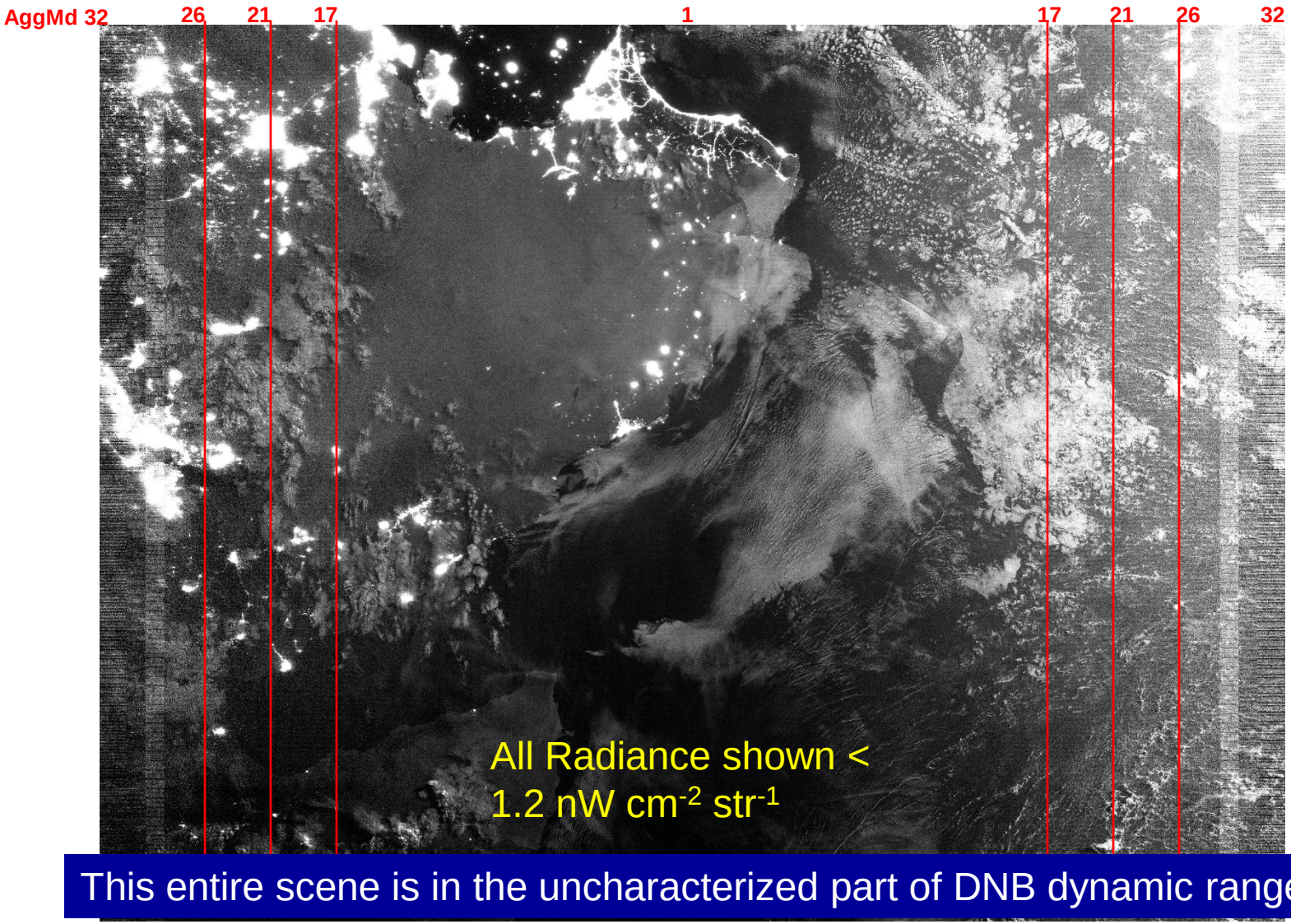
Part 1 -DNB Nonlinearity for Very Low Radiance High-Gain Stage(HGS)

Background for High-Gain Nonlinearity

- DNB Radiometric tests at Raytheon
  - Radiometric response was measured for DNB in RC2-Part4 test for radiances from 1.4 nW $cm^{-2}str^{-1}$ to 56 mW $cm^{-2}str^{-1}$
  - Severe nonlinearities were observed in high gain stage (HGS) for Aggregation Modes(AggMd) 27 to 32 near edges of swath
  - Correctable nonlinearity observed in 4 detectors for AggMd 22 to 26
  - Two options to eliminate or correct nonlinearities were proposed & tested
    - Option 21 would extend AggMd21 to the edge of swath reducing resolution by 56% at edge
    - Option 26 would extend AggMd21 to replace AggMds 22-25, and AggMd26 to edge of swath reducing area resolution by 26% at edge of swath
- Response not measured for low radiance < 1.4 nW $cm^{-2}str^{-1}$
  - VIIRS requirements define performance only down to 3 nW $cm^{-2}str^{-1}$ (L_{min})
  - Quarter moon illuminated scenes typically < 1.4 nW $cm^{-2}str^{-1}$
  - Astronomical twilight, airglow & auroras scenes typically < 1.4 nW $cm^{-2}str^{-1}$

We lack knowledge of an important part of DNB dynamic range

Quarter Moon Scene—16 Sep 2014

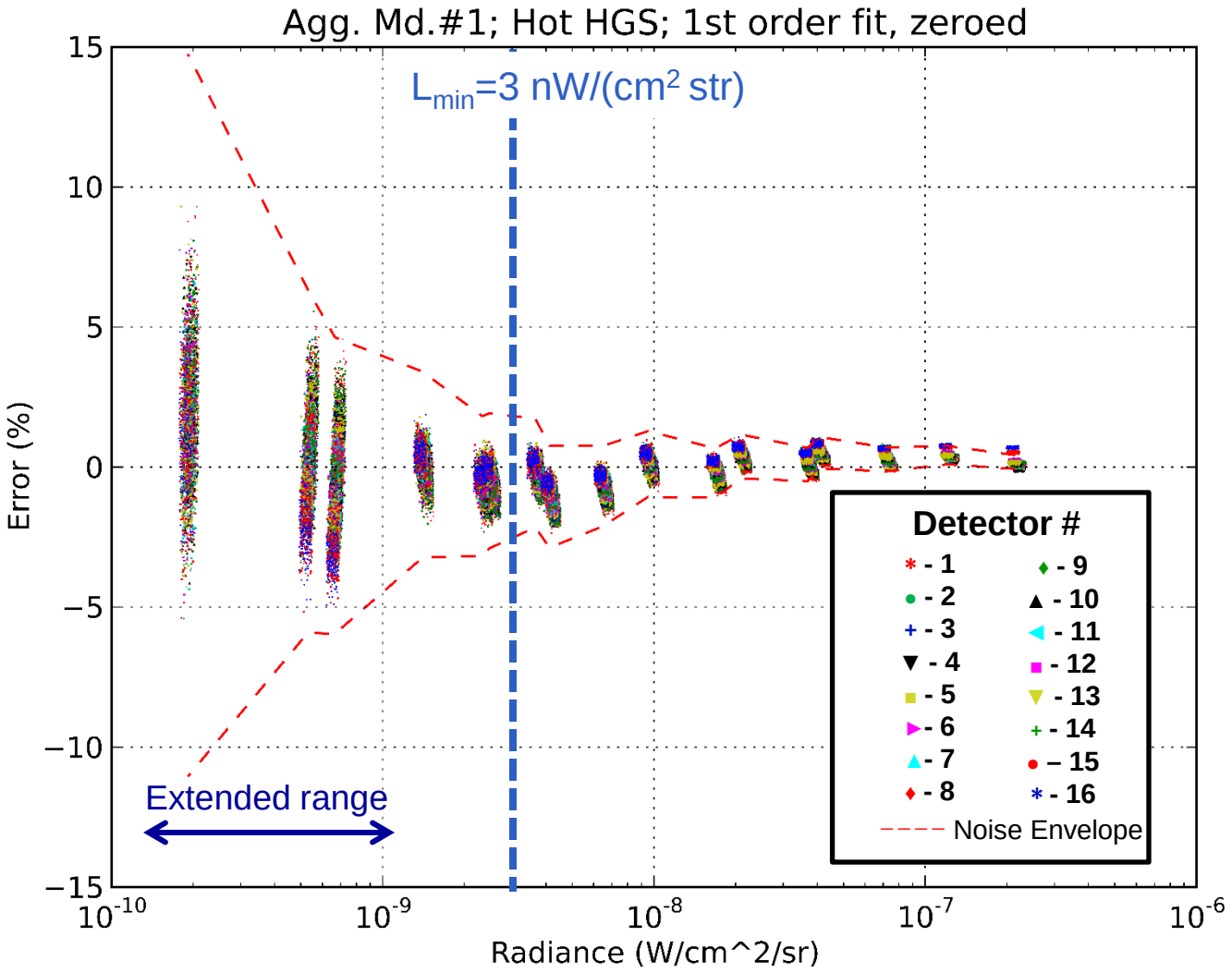


This entire scene is in the uncharacterized part of DNB dynamic range

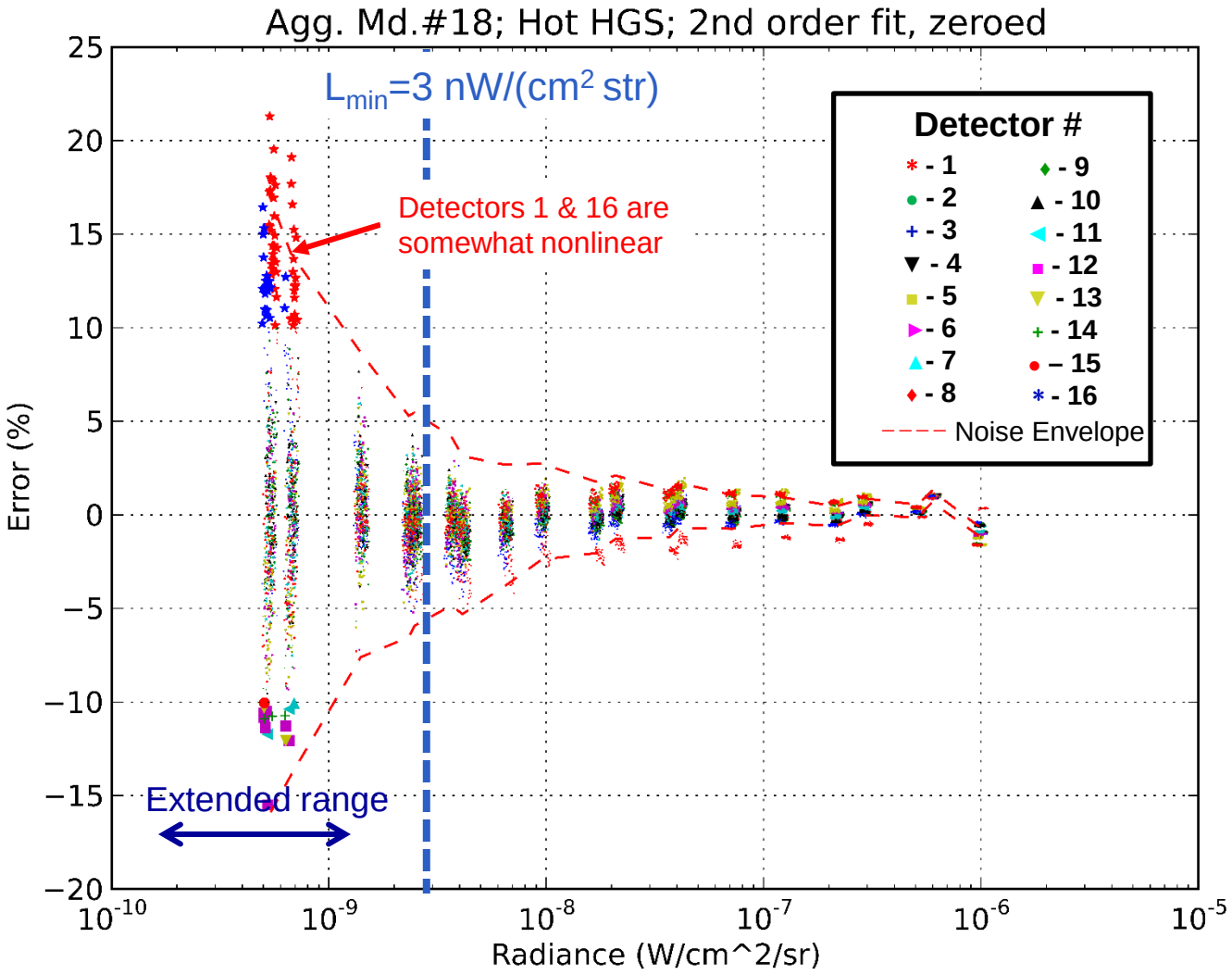
How to determine radiometric response at these very low radiances?

- The “space view” reference signal at the highest LGS illumination levels has laboratory stray light in the HGS range
  - The “space view” calibrator is black, but has a small reflectance
  - This stray light signal for highest level LGS was about at the same counts in HGS as the lowest radiance level of 1.4 nW $cm^{-2}str^{-1}$
- The stray light signal can be estimated as a fraction of the total SIS illuminator signal
  - The factor was determined to be a constant 9.75×10^{-7} (a good stray-light suppression factor)
  - With this it is possible to characterize the dynamic range down an additional order of magnitude to 0.1 nW $cm^{-2}str^{-1}$
- This extended range does not appear in Raytheon’s official performance results

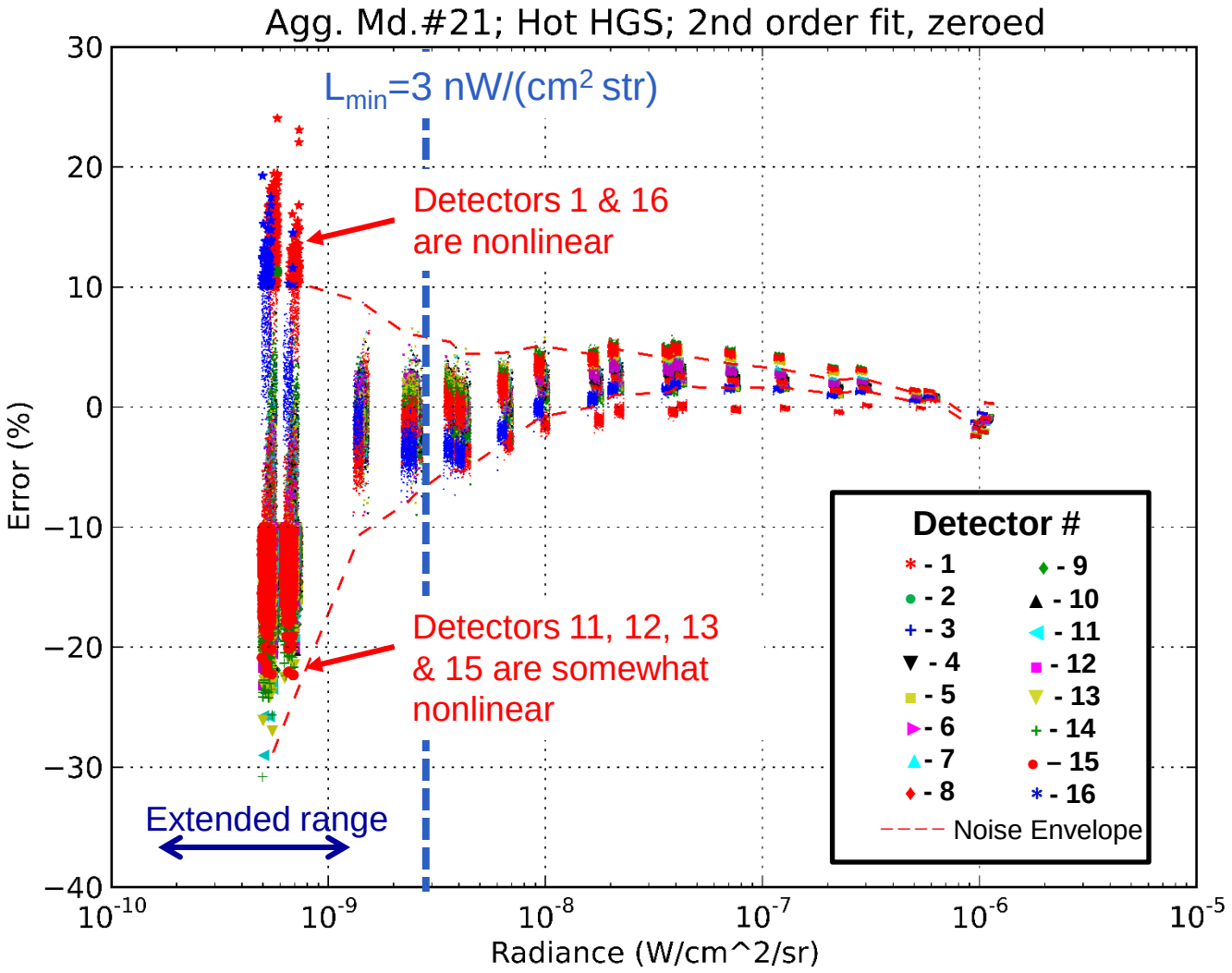
AggMd 1 (near nadir) is very linear



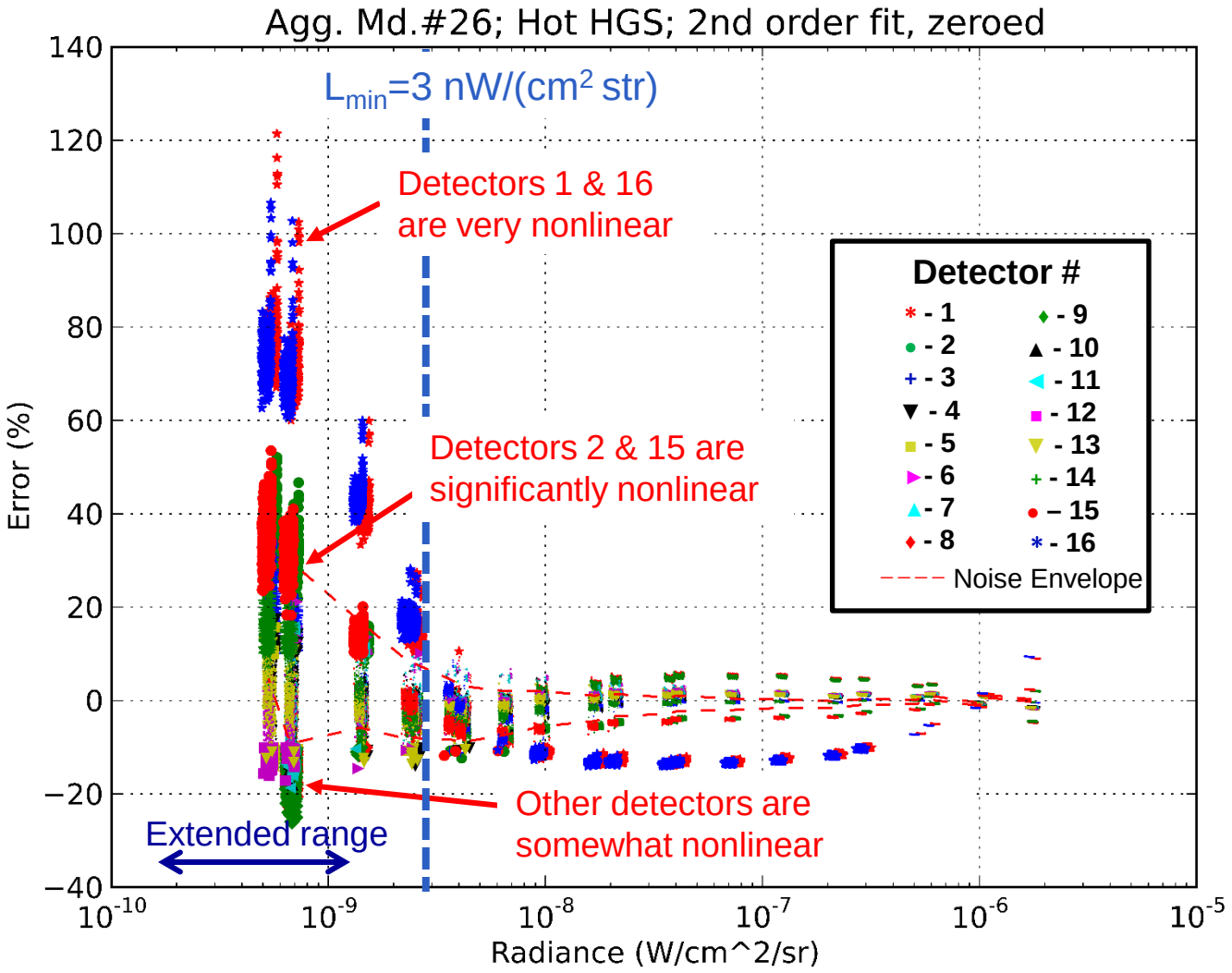
AggMd 18 has some nonlinearity



AggMd 21 (from Option 21) has significant nonlinearity



AggMd 26 (in Option 26) has strong nonlinearity



Conclusions

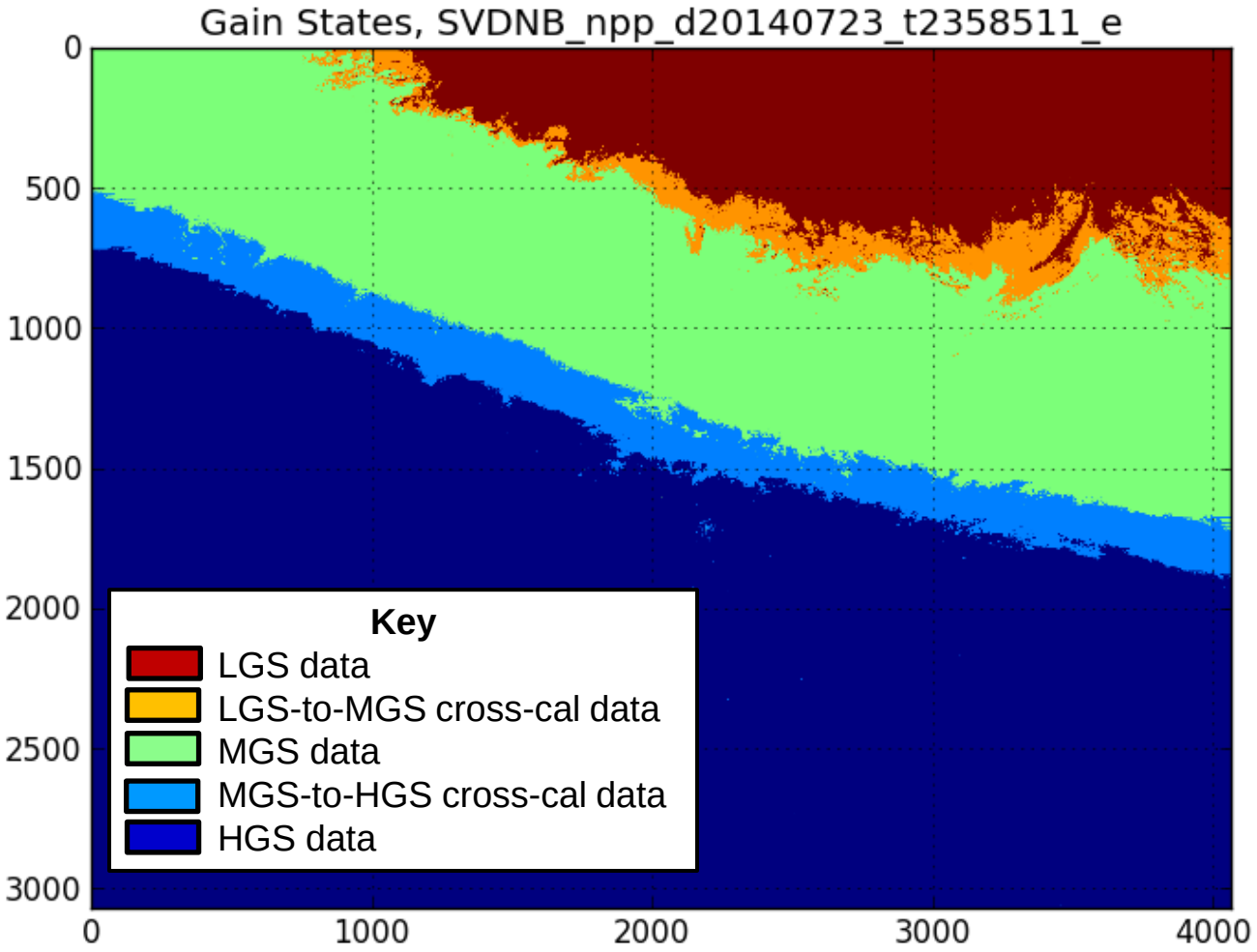
- DNB radiometric response characterized for radiance as low as 0.2 nW cm^{-2} str^{-1}
  - Source was extended with the stray laboratory light reflecting off the “black” space view
- In HGS Aggregation Modes 1 to 16 are linear for all 16 detectors
- For Aggregation Modes 17 to 21 several detectors are somewhat nonlinear
- Agg Mode 26 has 4 very nonlinear detectors 1,2, 15 & 16
- These nonlinearities will result in striping for Quarter Moon scenes affecting 39% of swath
  - Even some of full moon scenes, in twilight scenes and air glow illuminated scenes

Part 2—Computation of DNB Gain-Ratio Calibration Errors

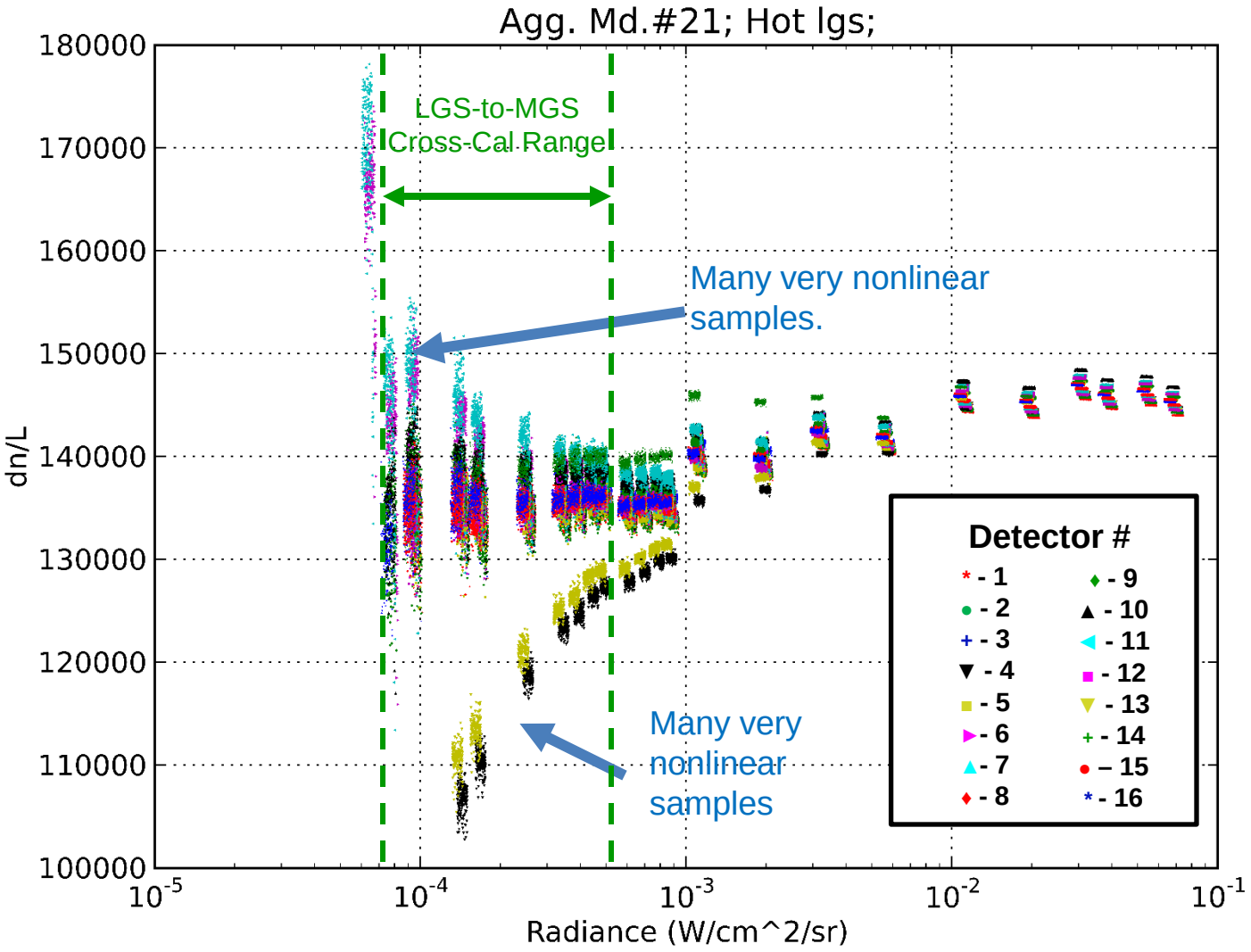
Gain-Stage Cross Calibration

- Only the low gain (LGS) is calibrated using the solar diffuser (SD)
  - Process is similar to the other VIIRS reflective solar bands (RSB)
  - Mid gain and high gain saturate when the sun is illuminating the SD so cannot be directly calibrated from SD
- Gain transfer to MGS & HGS uses special process, VROP 705, viewing twilight region around day-to-night terminator crossing
  - Day-to-night mode transition is started earlier while VIIRS still viewing daylight,
  - Process is currently performed once per lunar month
  - Additional data is transmitted so that all gain stages are available
  - Unfortunately, due to this process gain and uniformity errors from lower stages transfer to higher stages
- This presentation uses the RC2-Part 4 data to estimate calibration errors due to Gain-Stage cross-calibration

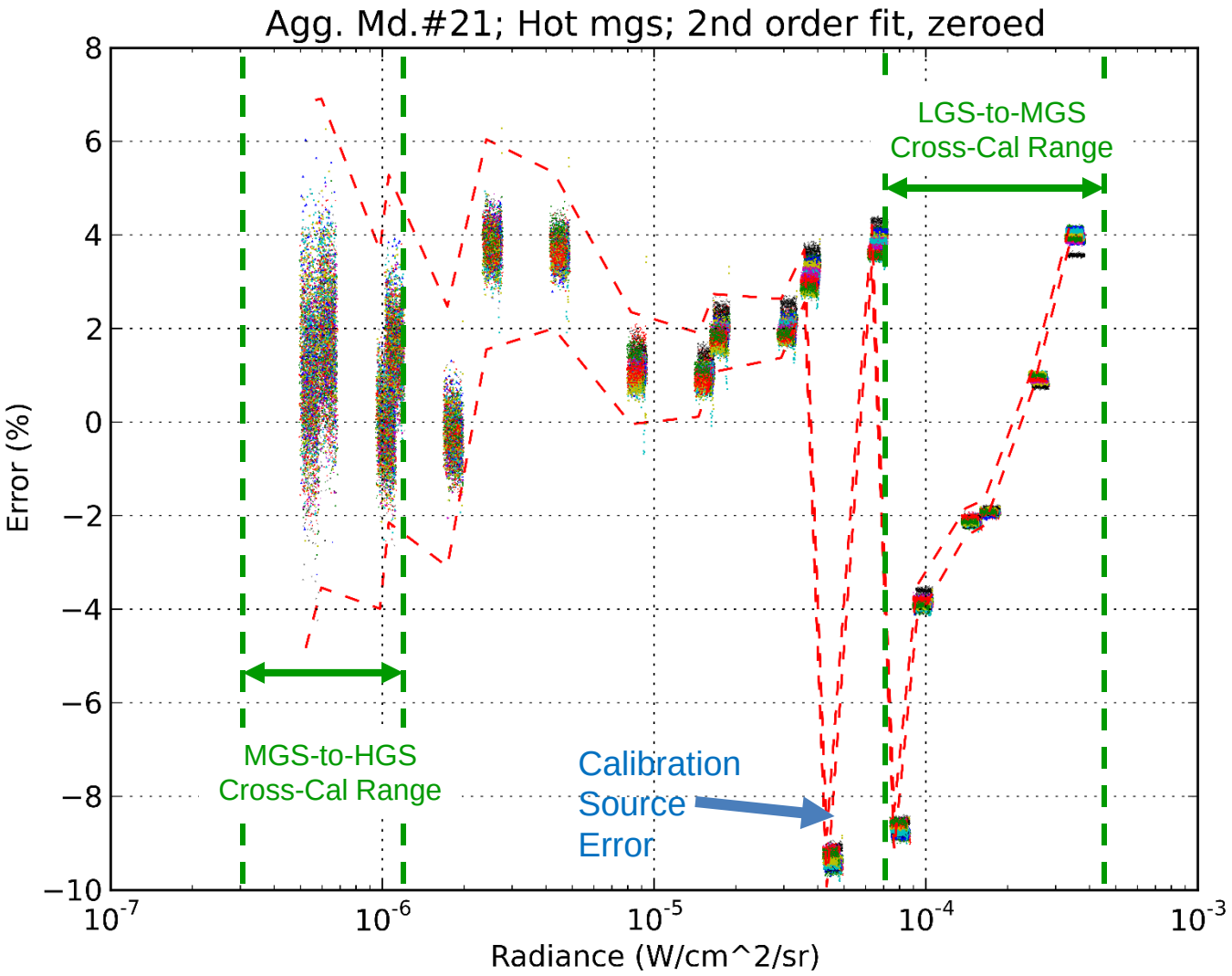
Typical VROP 705 Data—23 Jul 2014



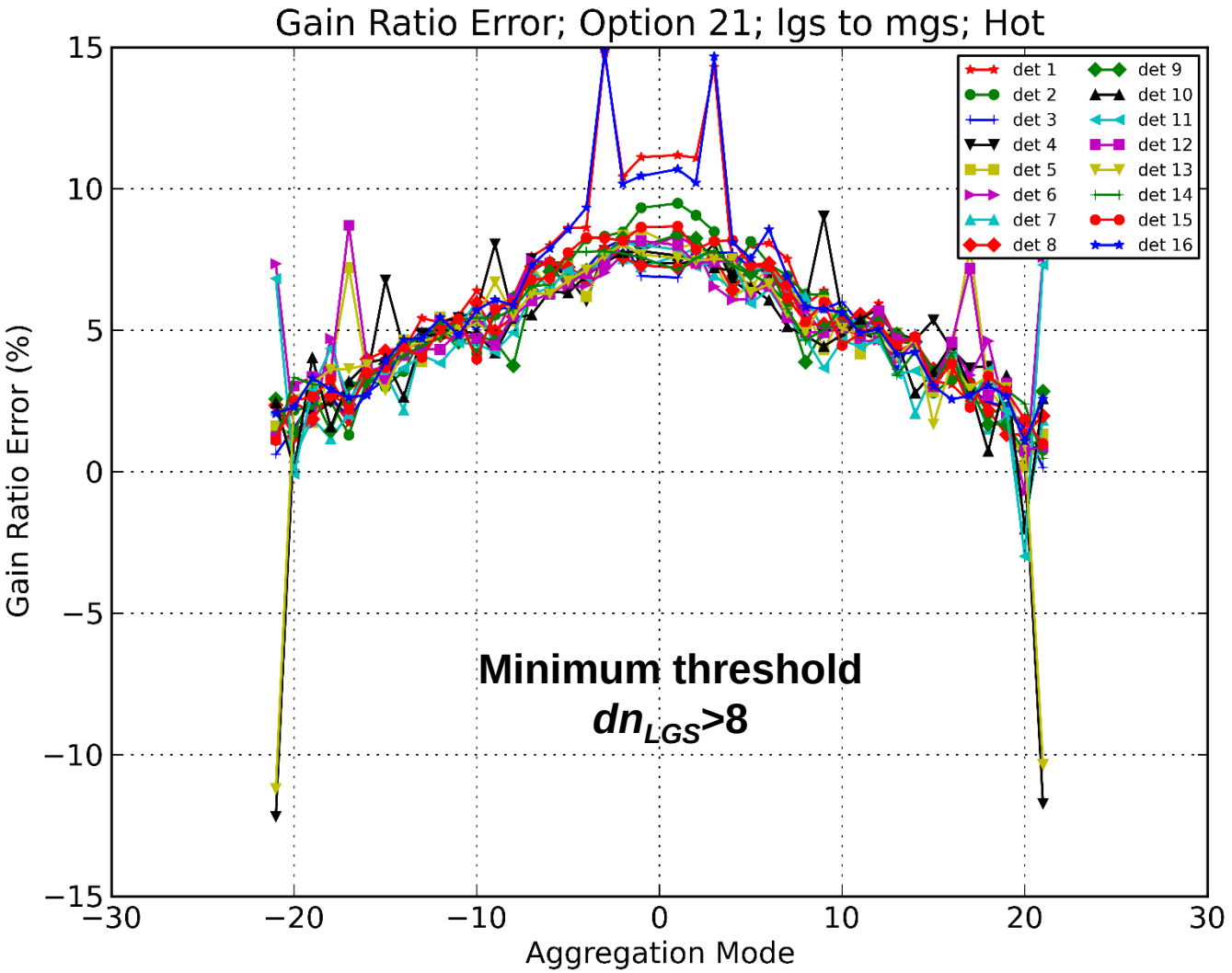
Example of LGS Nonlinearity



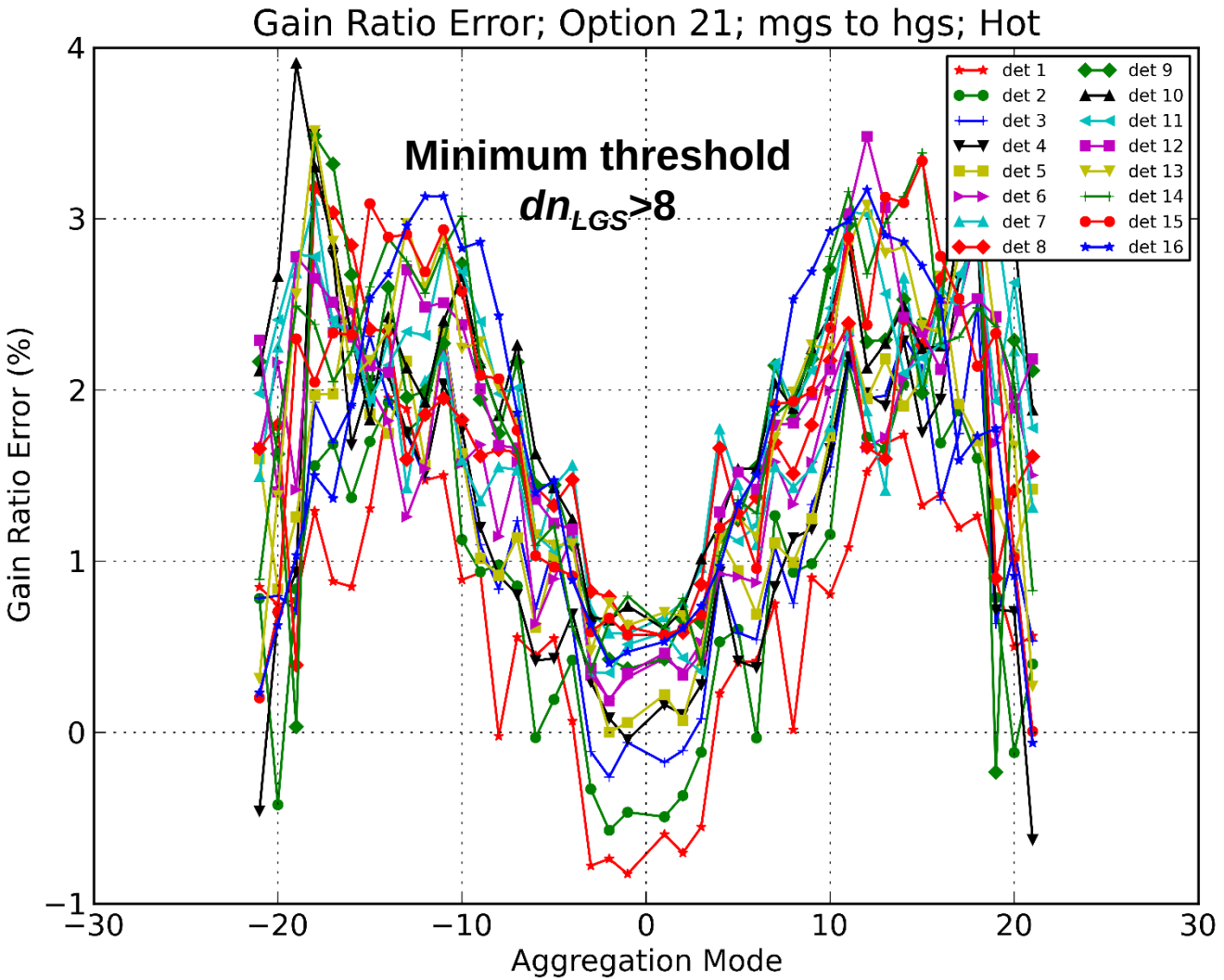
Example of MGS Nonlinearity



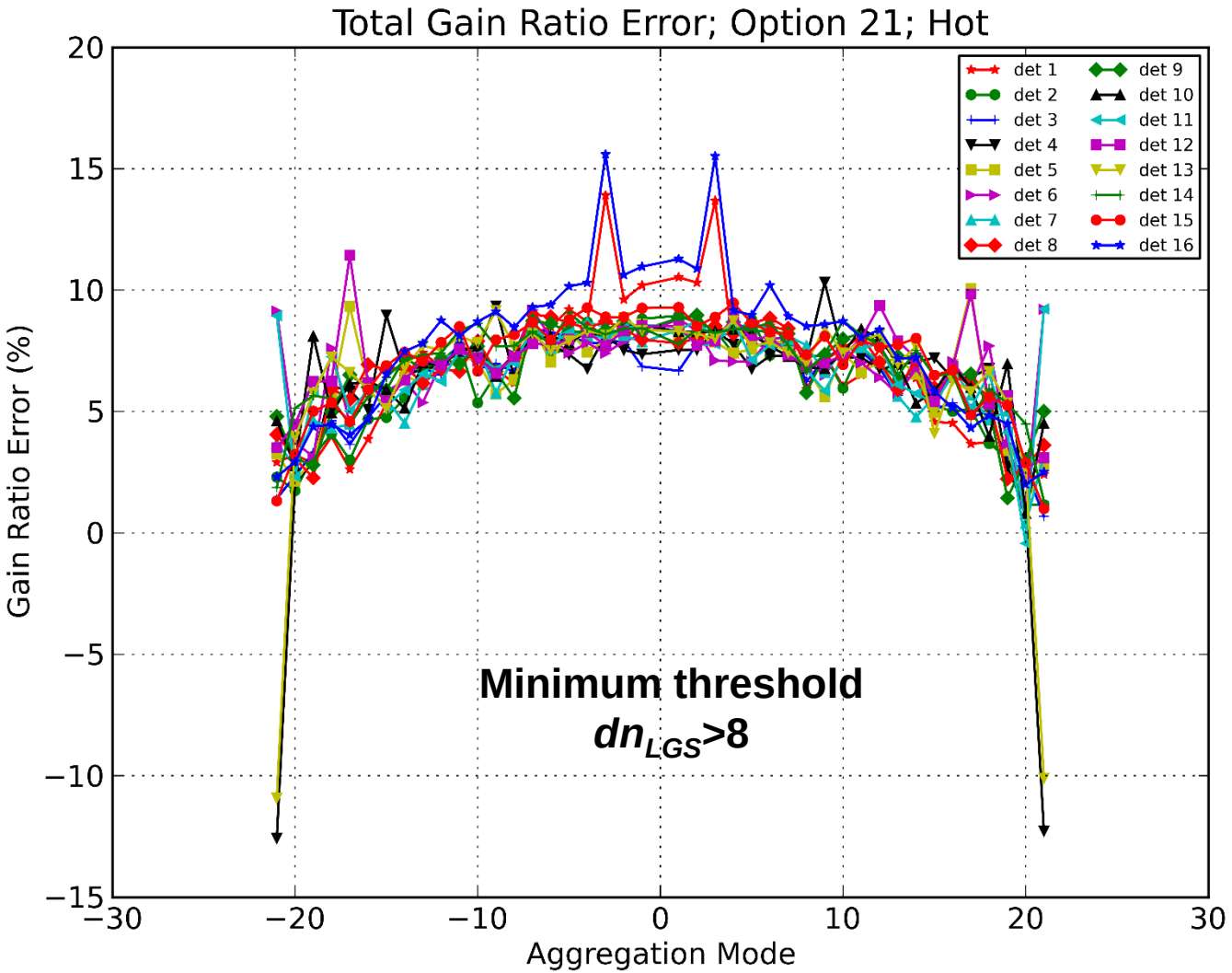
LGS-to-MGS Gain Ratio Errors



MGS-to-HGS Gain Ratio Errors



LGS-to-HGS Total Gain Ratio Errors



Observations

- Most gain errors are positive, which will cause a negative bias in radiances of MGS and HGS
  - Bias is averages about 8% at nadir
  - Bias decreases to about 2% near edge of scan
  - This is due to higher detector gain in LGS for radiance < 1×10^{-4} W cm^{-2} str^{-1}
- For AggMds 1 to 20
  - AggMd 3 is a bad actor with det. 1 & 16 having gain errors 8% to 10% higher than other detectors
  - AggMds 9, 15 & 17 have one detector with about 5% out-of-family gain error
- AggMd 21 has 4 detectors that are bad actors in the LGS-to-MGS gain ratio
  - Det. 5 & 13 have gain errors that are 20% less than most of the others
  - Det. 11 & 12 have gain errors that are 5% > than most of the others

Conclusions & Recommendations

- With the current linear cross-calibration process, **all twilight and nighttime scenes** will have serious striping **regardless of the option chosen**, and impacts 34% of the swath in Option 21
- Striping magnitude exceeds the uniformity requirement in:
  - AggMd 21 for MGS & HGS over entire dynamic range with a total spread of 26%
  - AggMd 3 for MGS & HGS over entire dynamic range with a total spread of 8%
- For HGS & MGS there is a bias of up to 8% that peaks at nadir
- These errors are not related to and will **not be mitigated** with a dual range calibration change
- **Recommendation:** Change the current the cross-calibration process to use characterization of DNB nonlinearities from RC2-Part 4.

Part 3—Simulations of Nightime Imagery with Calibration Errors

Simulation Methodology

- 7 S-NPP night time scenes are used from 3 dates
- Destriping algorithm is applied to produce a pristine reference scene
  - Destriping algorithm is described in S. Mills & S. Miller, "VIIRS Day-Night Band (DNB) calibration methods for improved uniformity," SPIE 9218-7, 2014
  - Very low-level uncorrected striping remains in these "pristine scenes"
- Residual errors (shown in part 1)are computed for each radiance level and saved as a table
  - Calibration coefficients are derived from radiometric Tvac test data
  - 2nd order fit for calibration coefficients, per detector, per Agg. Mode
  - Fit constrained to zero at zero *dn*
  - Radiances from SDR are used to linearly interpolate residual error
  - Residuals errors are added to radiance
- LGS-to-HGS total gain ratio error are computed as described in Part 2 of this presentation
  - RC2-Part4 test data from the hot plateau is used
  - Errors are saved in a table by detector and aggregation mode
  - Each pixel's radiance is multiplied by a gain ratio error factor

7 Test Scenes

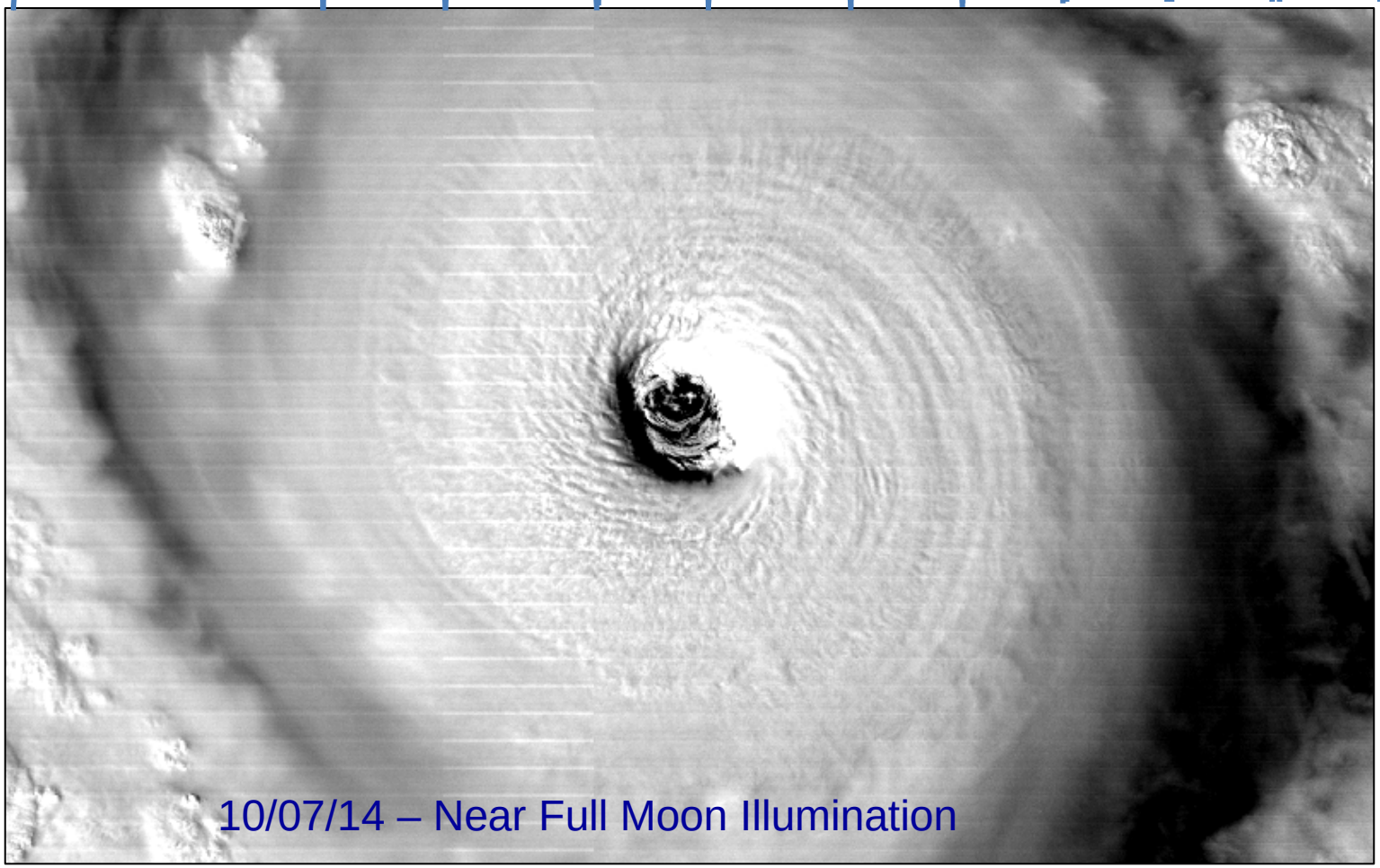
All scenes shown are 375 km in-track by 600 km in-scan:

1. 10/07/14 (Lunar phase nearly full), Typhoon Vongfong
2. 09/09/14 (Lunar phase nearly full), Parts of Sudan & Red Sea
3. 09/09/14, (Lunar phase nearly full), Parts of Alaska, Yukon & Arctic Ocean
4. 09/16/14, (Lunar phase—last quarter), Clouds over Seward Peninsula, Alaska
5. 09/16/14, (Lunar phase—last quarter), Northern Libya and Mediterranean Sea
6. 09/16/14, (Lunar phase—last quarter), Southern Egypt
7. 09/09/14 (Lunar phase nearly full), Parts of Arabian Peninsula & Persian Gulf

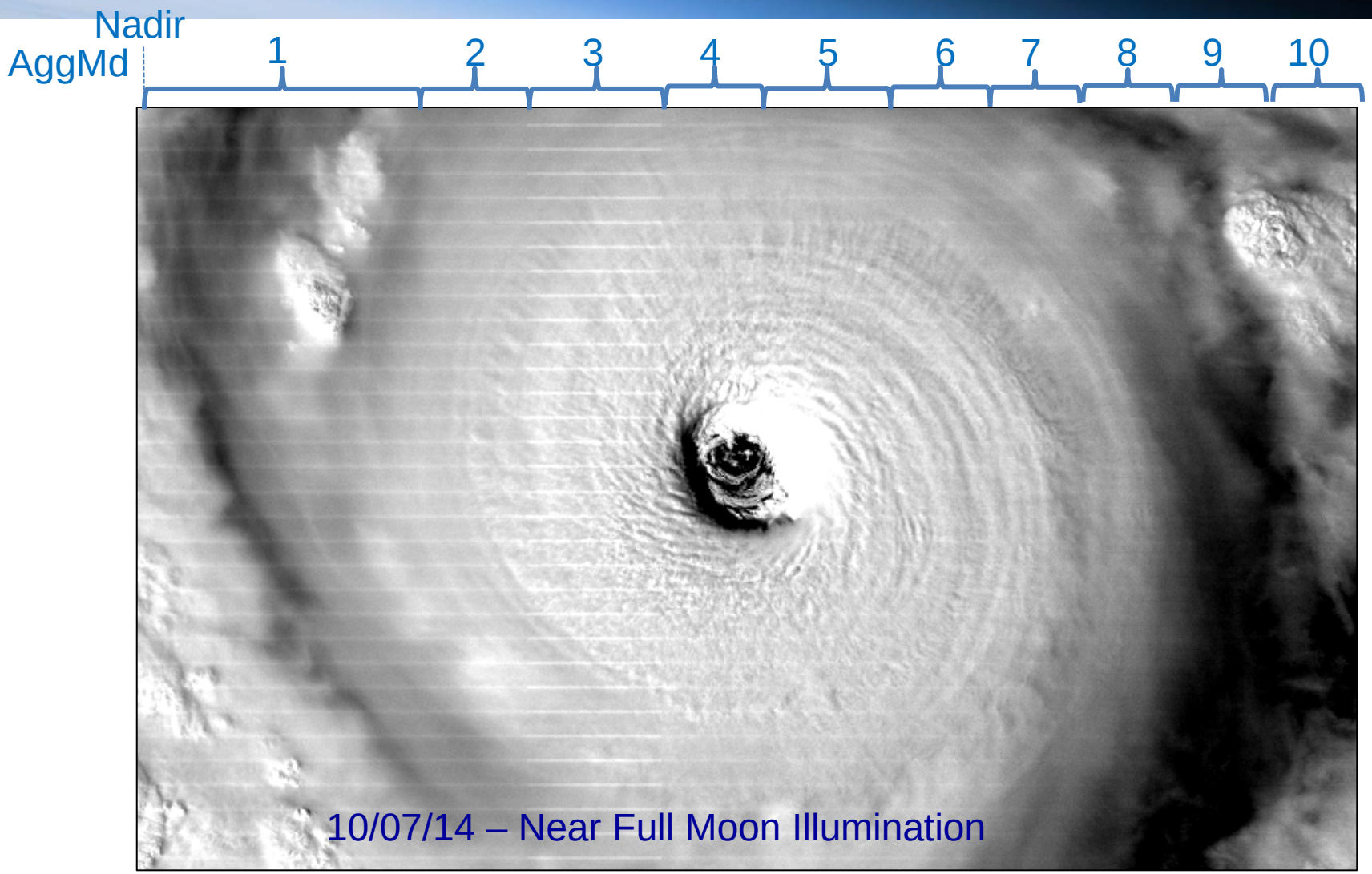
Vongfong, Pristine (destriped) Image

Radiance range grayscale: black=12; white=30 nW cm^{-2} str^{-1}

Vongfong, Simulated JPSS-1



Vongfong, Actual S-NPP Image



Scene 2, Sudan & Red Sea

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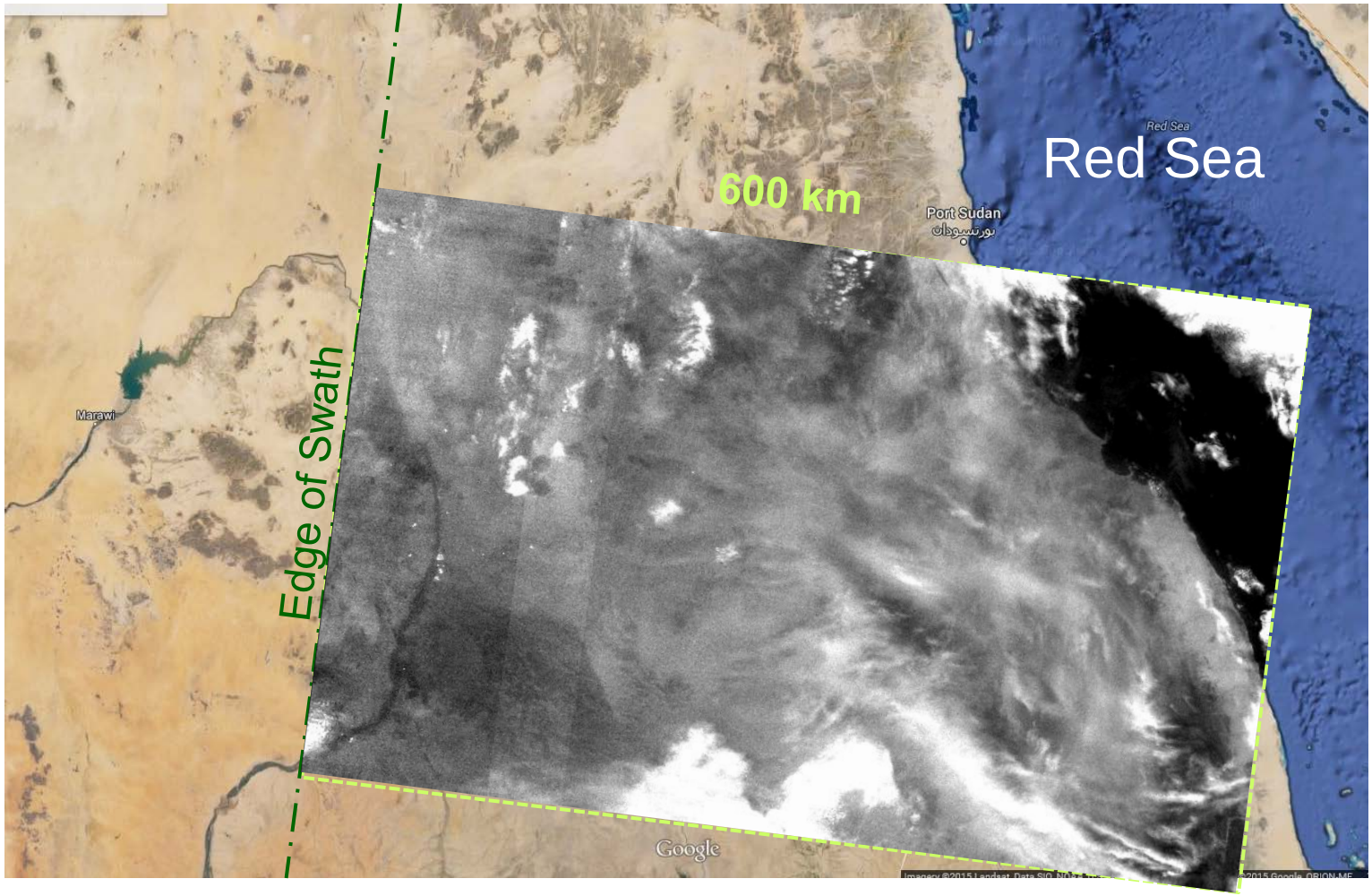
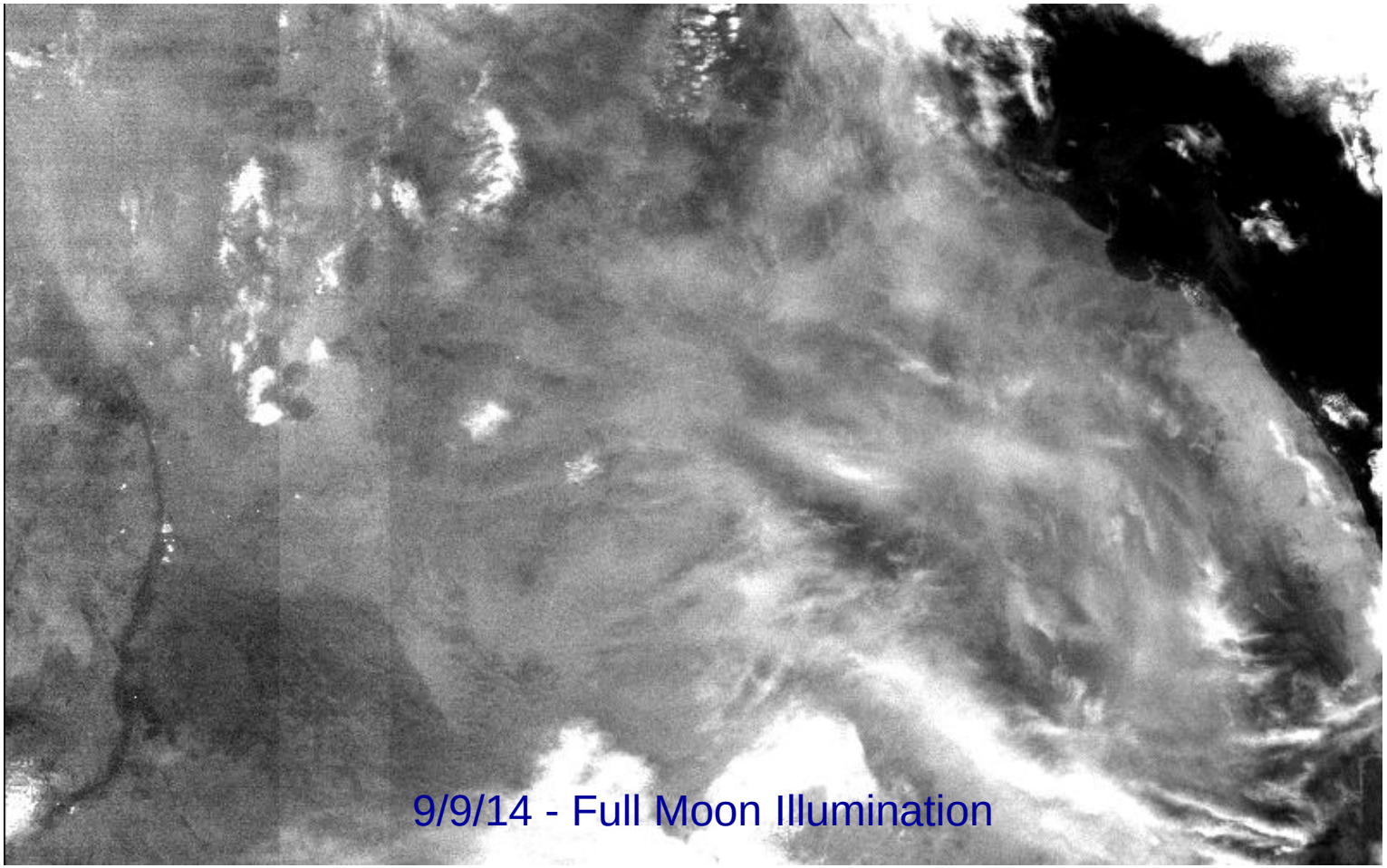


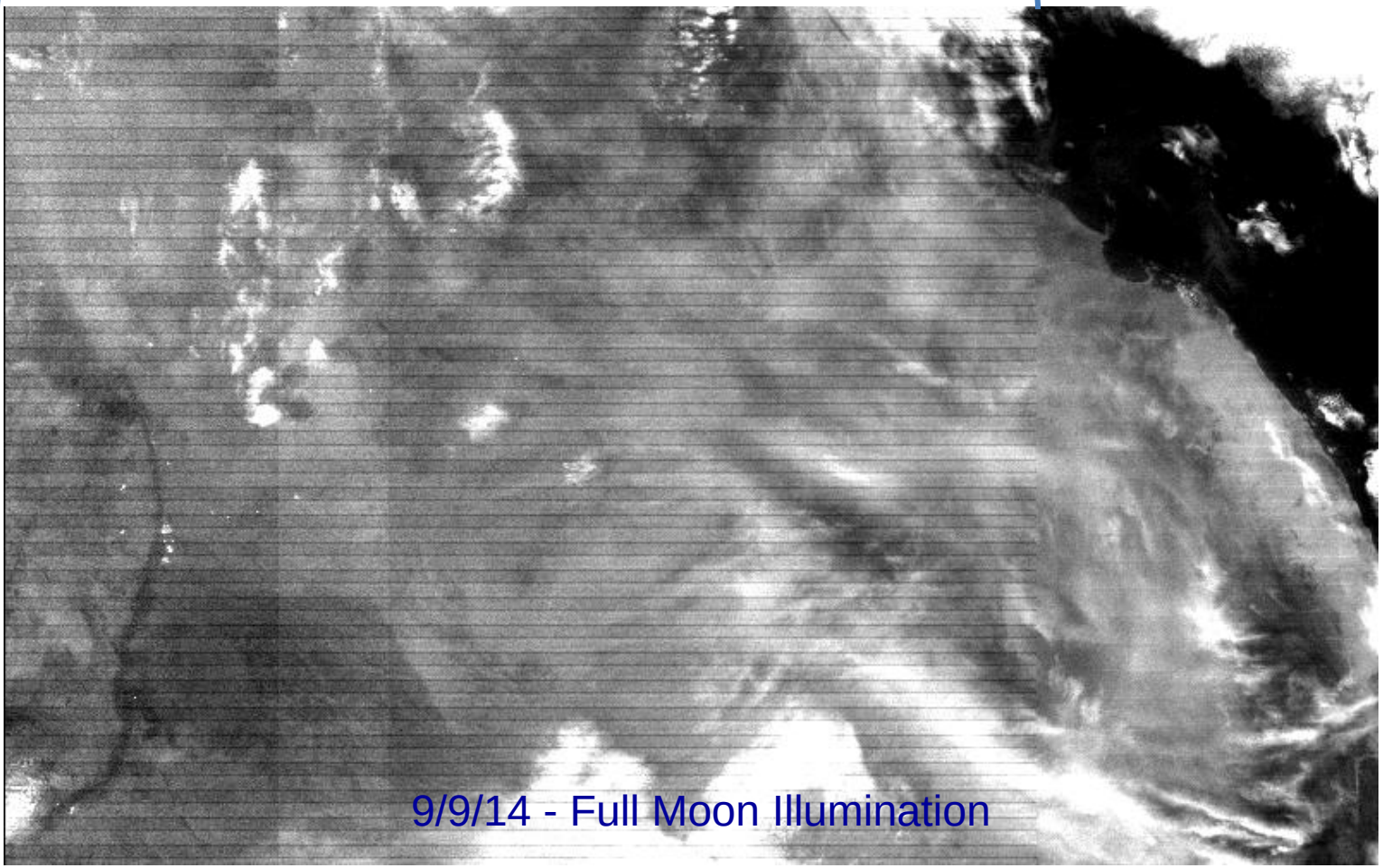
Pristine (destriped) Image



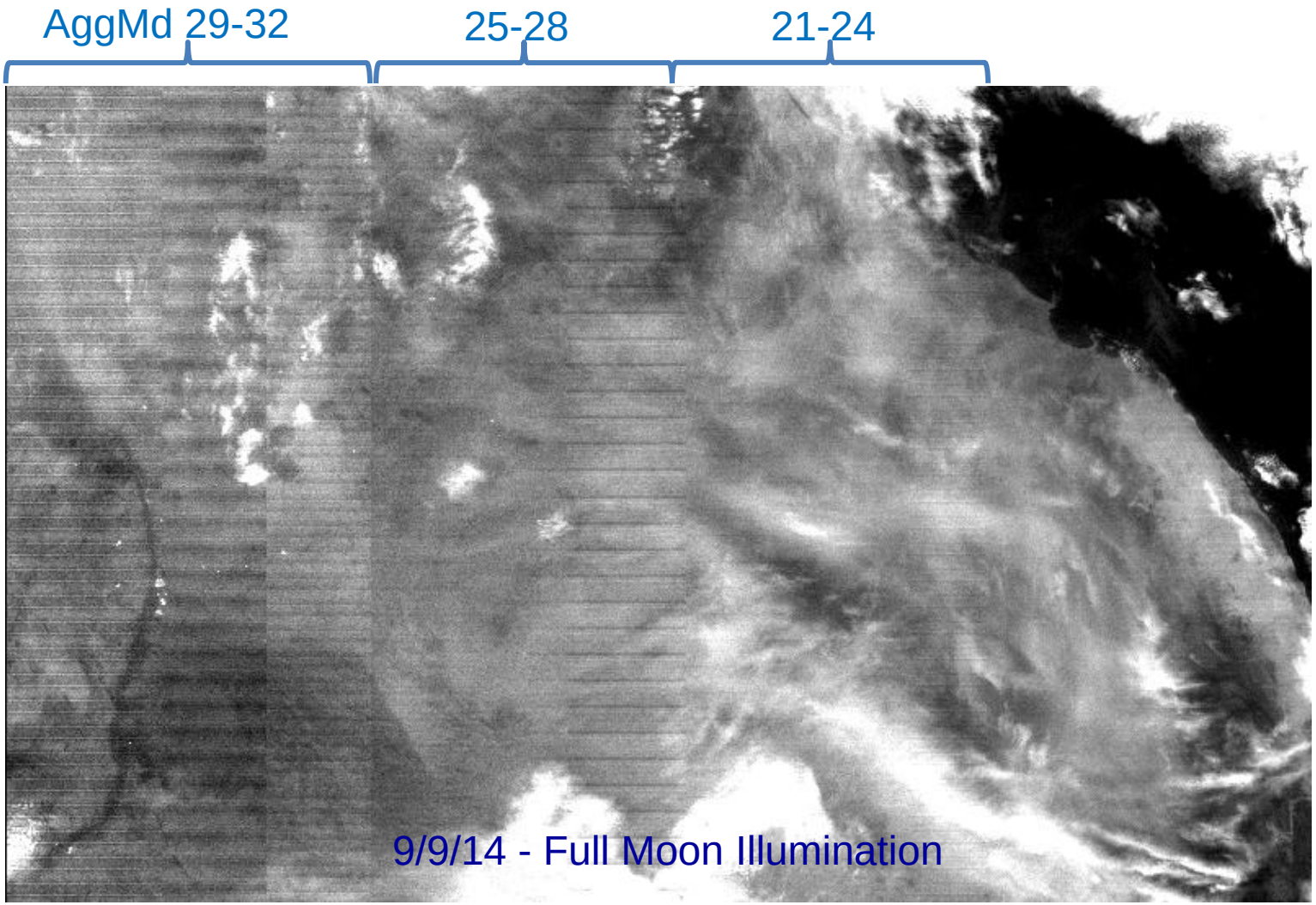
9/9/14 - Full Moon Illumination

Simulated JPSS-1, Option 21

AggMd 21

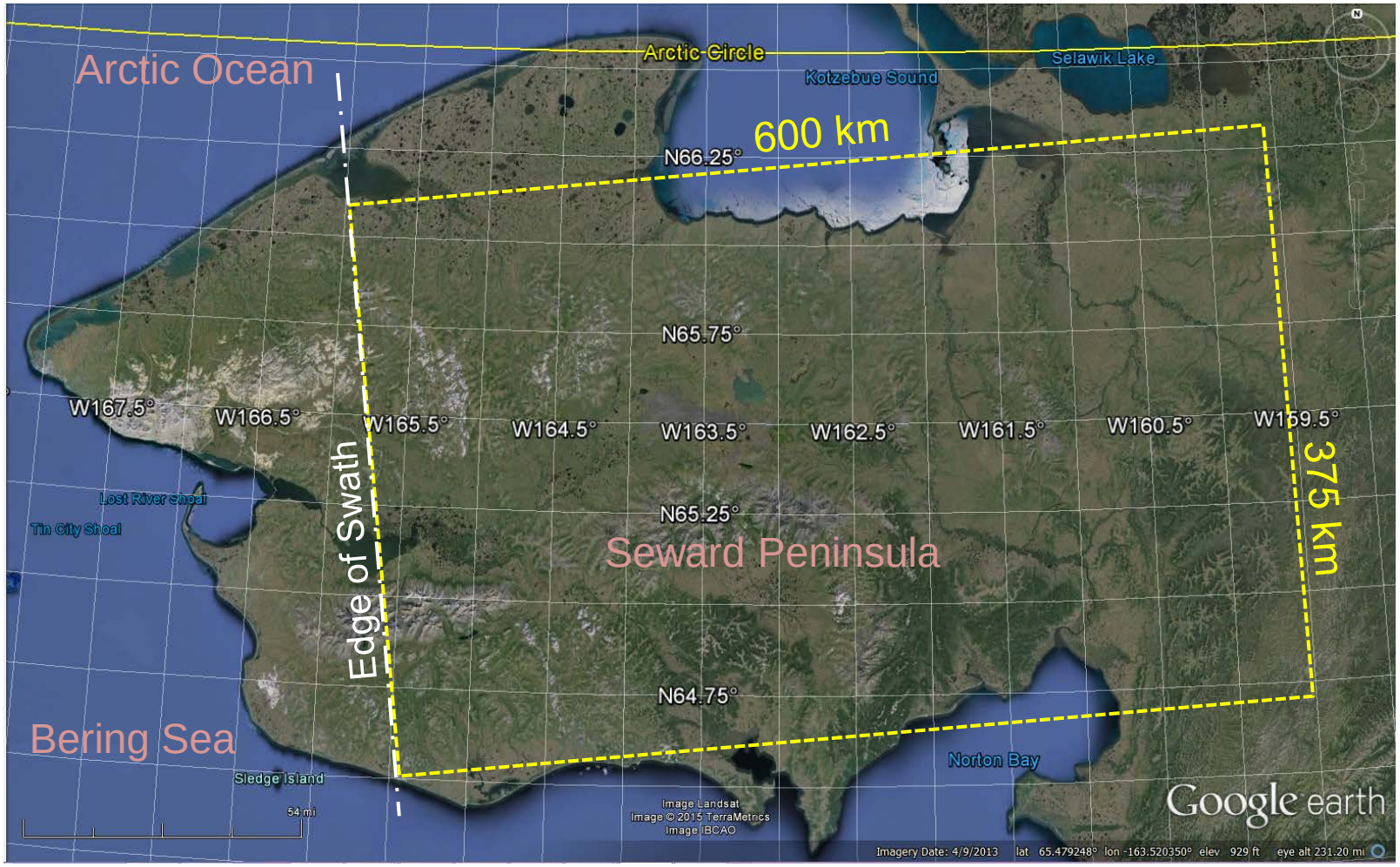


S-NPP Image with Striping

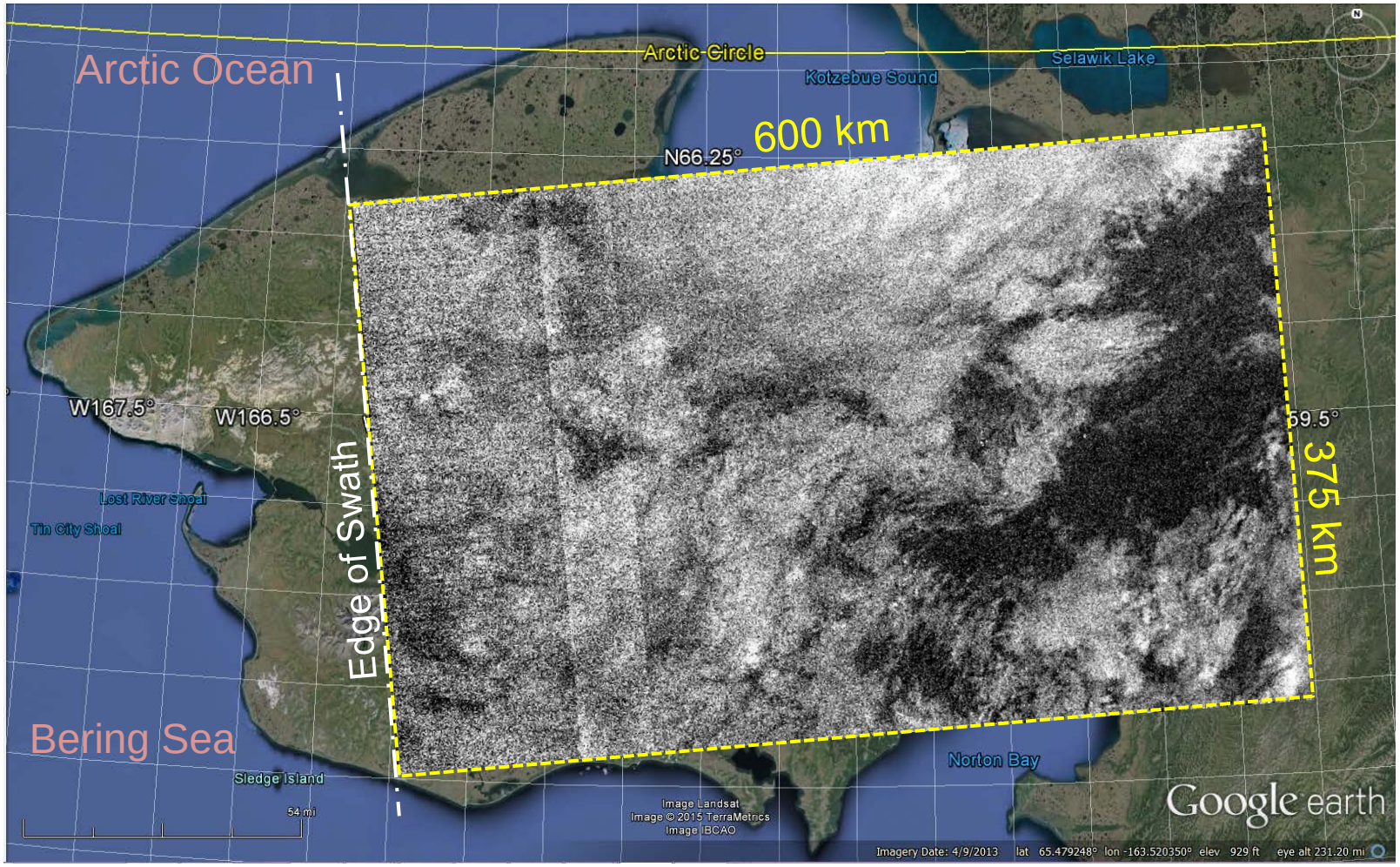


S-NPP has less striping near edge of scan than JPSS-1

Scene 4-Last Quarter, 9/16/14
Clouds over Seward Peninsula, Alaska

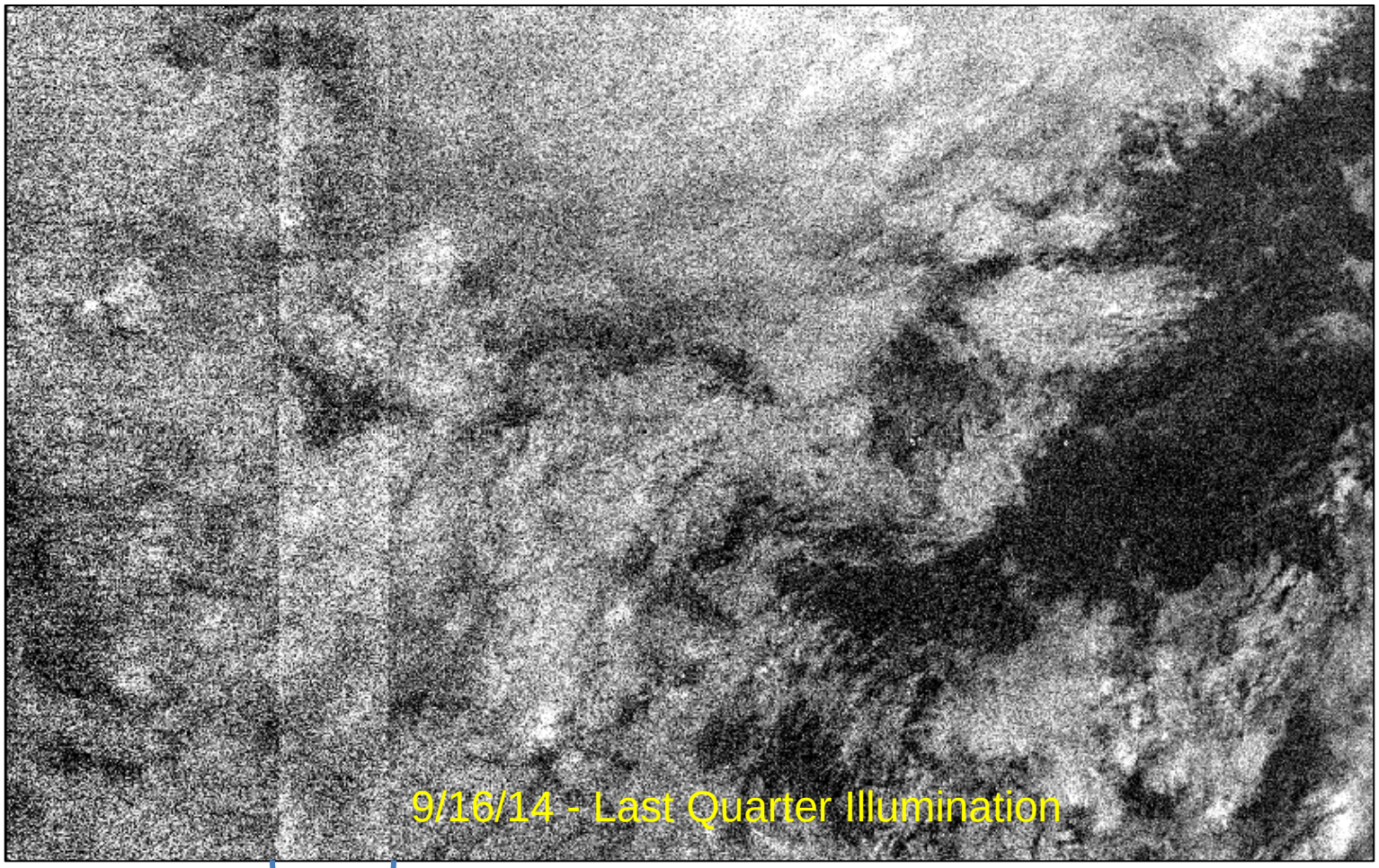


Scene 4-Last Quarter, 9/16/14
Clouds over Seward Peninsula, Alaska

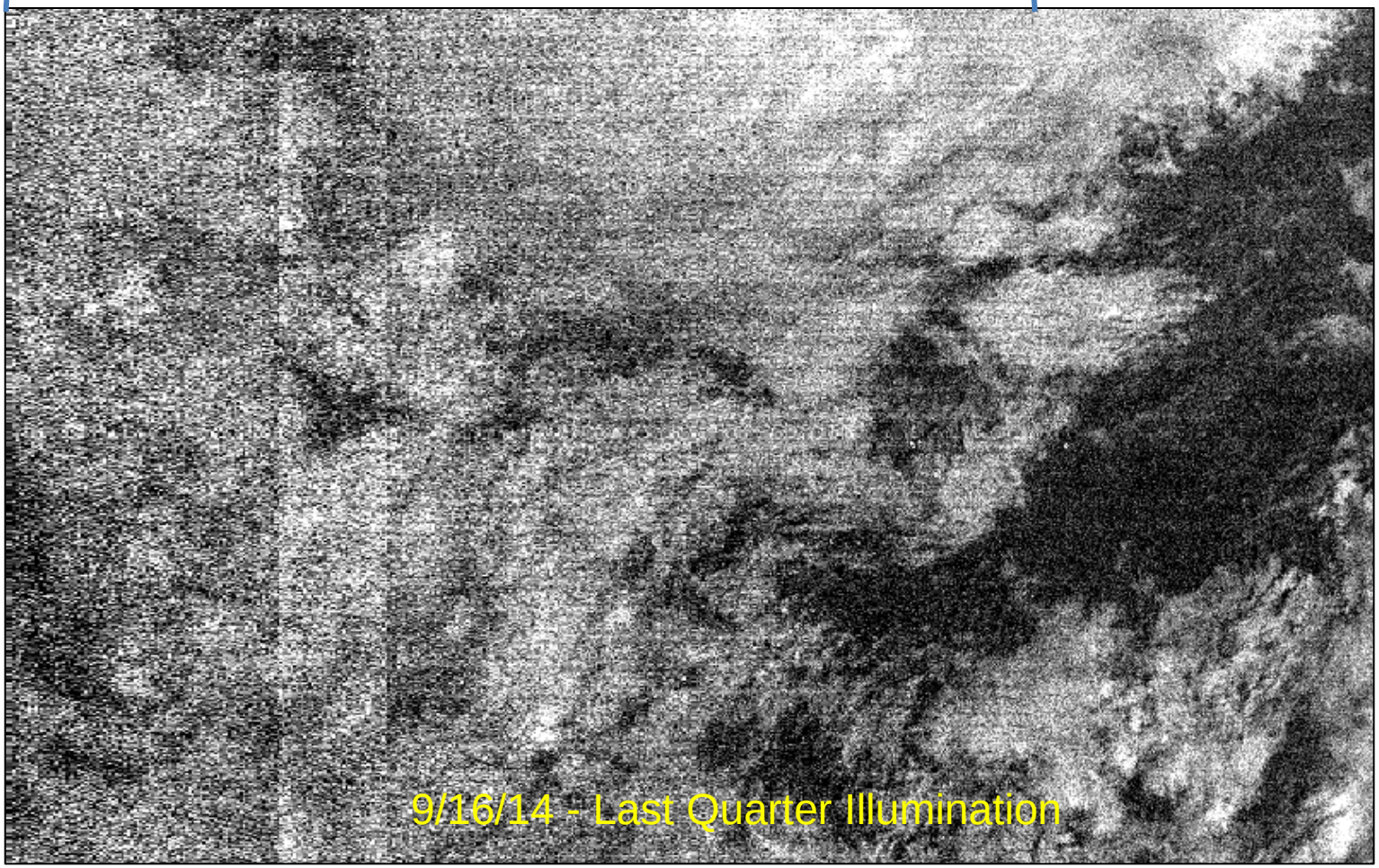


Pristine (Destripped) Image

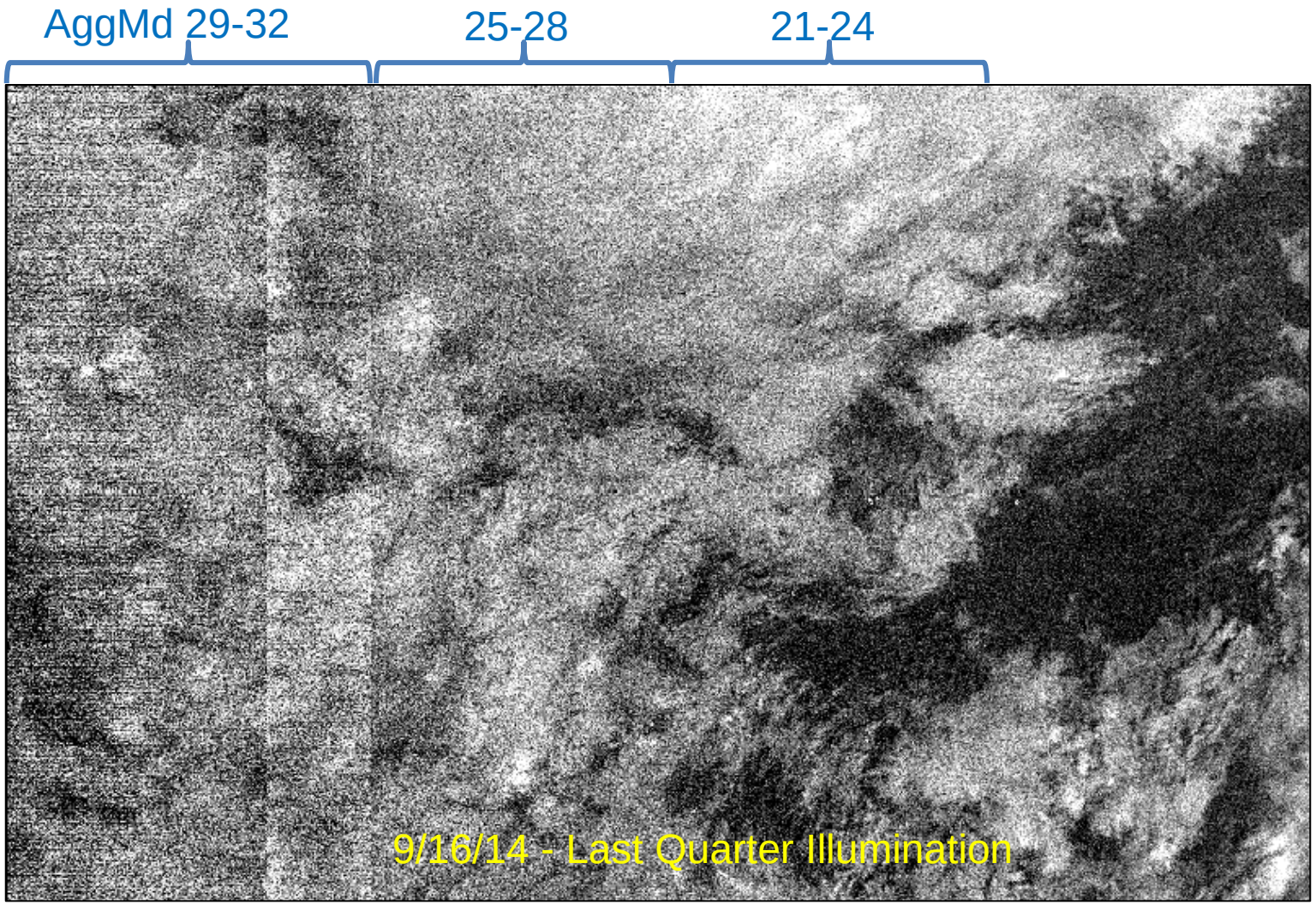
Radiance range grayscale: black=0.0; white=1.2 nW cm^{-2} str^{-1}



Simulated JPSS-1, Option 21



S-NPP Image with Striping



S-NPP has less striping near edge of scan than either JPSS-1 Option

Conclusions

- JPSS-1, even with Option 21, will have strong striping near edge-of-scan
  - It affects **30% of swath area**
  - This striping is much stronger than is seen in the same region for S-NPP
  - If this striping is not corrected it would represent a degradation of the imagery product relative to S-NPP expectations
- For JPSS-1 VIIRS the striping near nadir is very visible
  - Affects another **17% of swath area**
  - The magnitude of the near-nadir striping is similar to S-NPP
  - The S-NPP striping may be caused by these same nonlinearity errors in the cross-calibration
- In total, gain-ratio error causes striping in **47% of swath area**

Nonlinearity affects all 3 gain stages and for best results the cross-calibration should take this into account

Recommendations

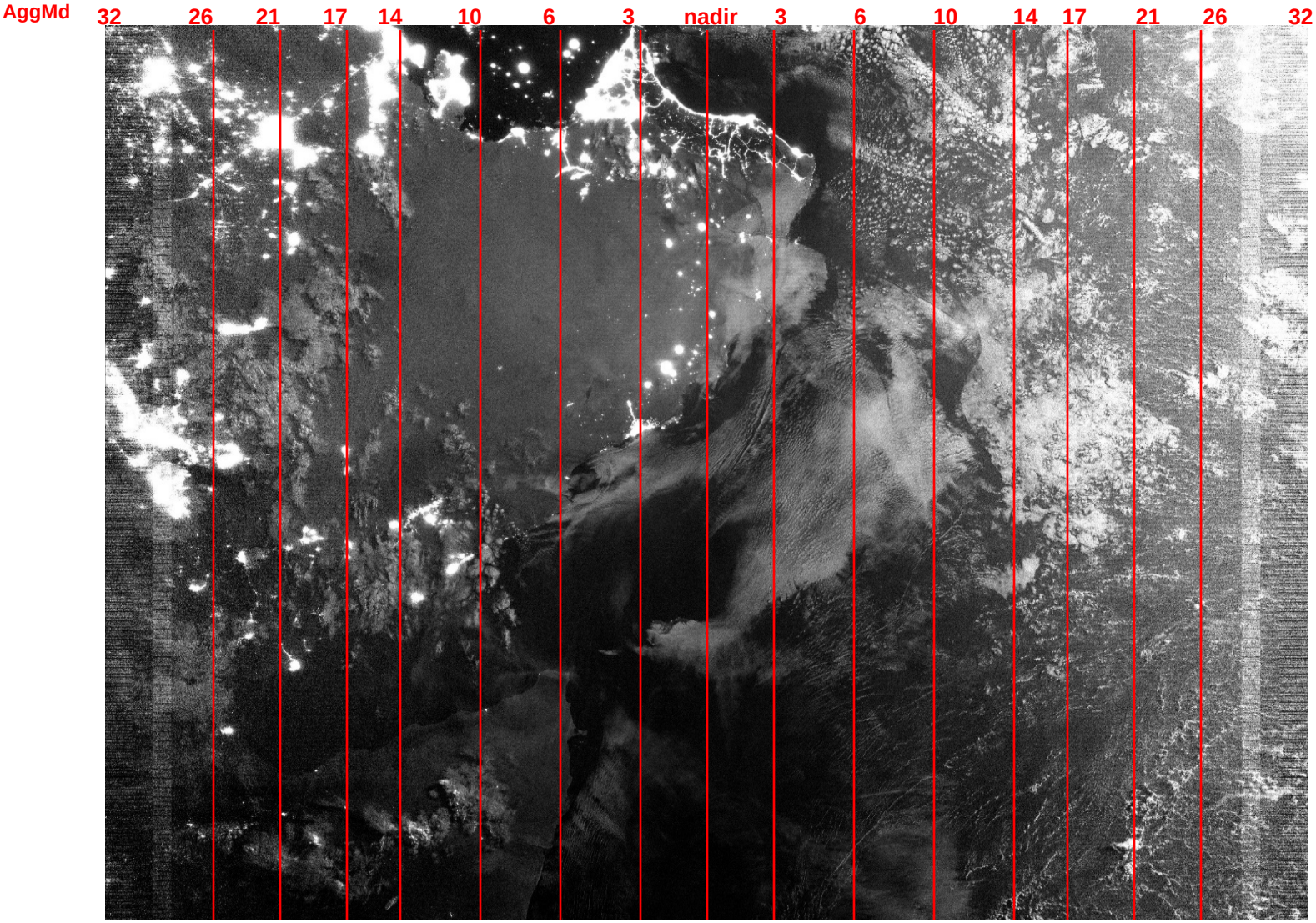
Almost all this striping could be eliminated with these calibration algorithm modifications:

1. Highest Priority - Modify gain-stage cross-calibration process (VROP 705) to include nonlinearity characterization
   - Will eliminate striping in nadir region for all options for 17% of swath
   - For Option 21 will eliminate almost all striping for 30% of swath at the edge
   - For Option 26 will eliminate almost all striping for 13% of swath at the edge
2. Modify the IDPS DNB SDR calibration algorithm to allow using a two-part quadratic fit for response correction
   - Combined with gain-stage cross calibration will eliminate almost all remaining striping
   - LGS twilight scenes: Will eliminate almost all striping for both Options 21 & 21/26
   - Nighttime scenes: For Option 26 will eliminate almost all remaining striping for 17% of swath at the edges
   - Would require changes to IDPS DNB calibration algorithm
3. Use Option 21 unless or until Recommendation #2 can be implemented
   - Striping would not, however, be fixed in LGS twilight scenes

If nothing is done JPSS-1 imagery will be **worse** than S-NPP

Back-up charts

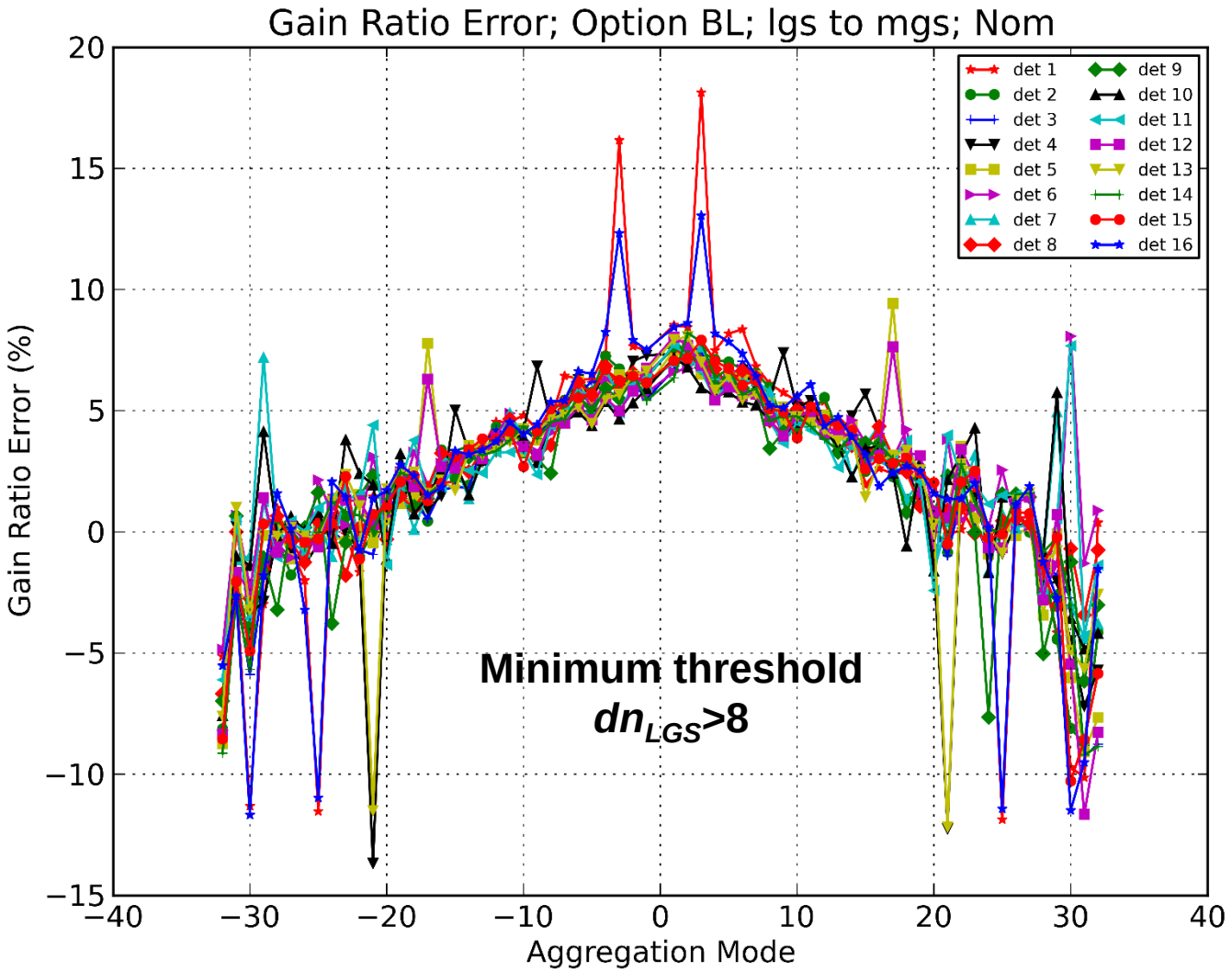
Aggregation Mode Locations



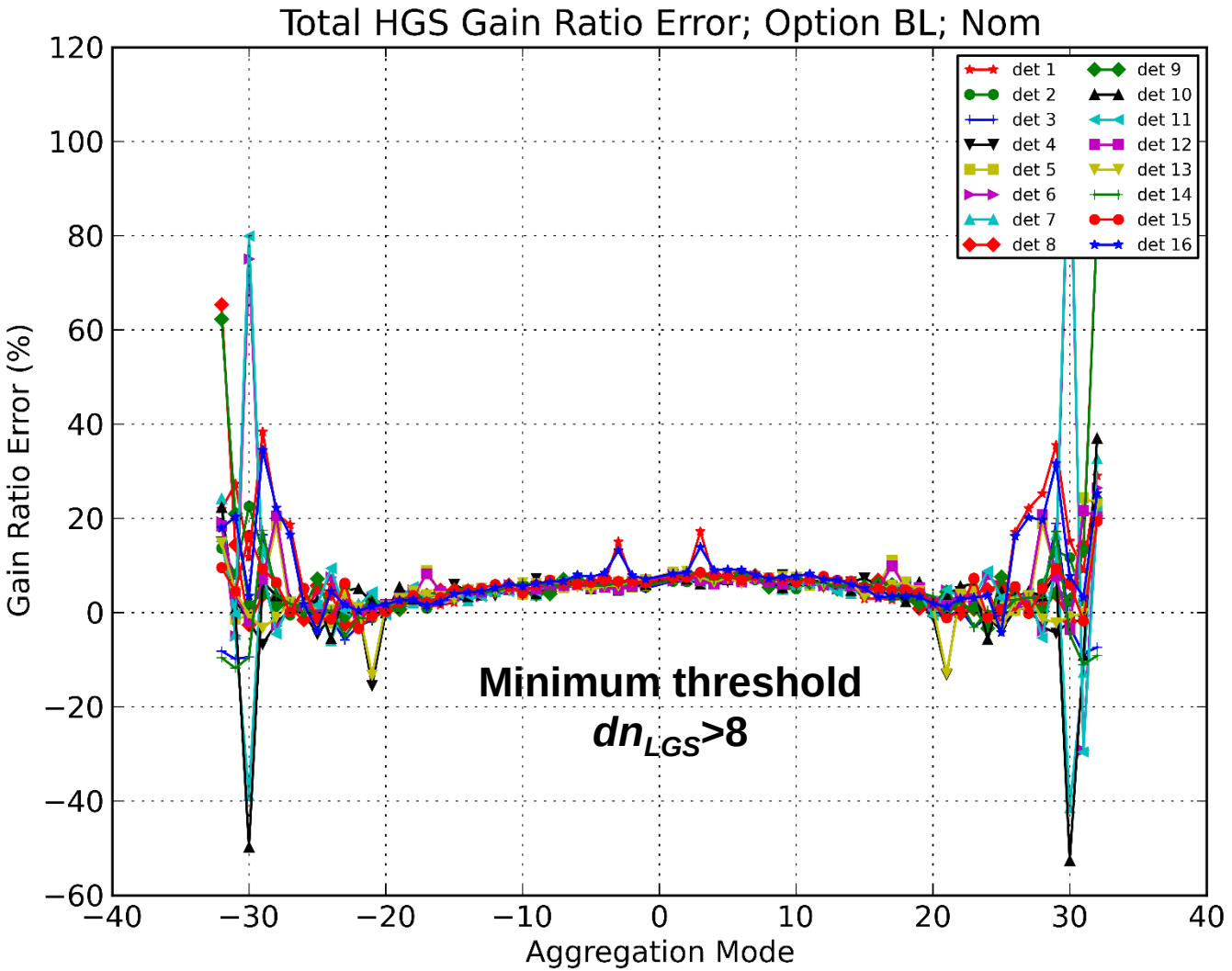
Computing cross-calibration Error

1. Determine response counts by subtracting the space view counts, so $dn_{sig} = (DN_{sig} - DN_{SV})$
   A. Compute for all lamp levels, detectors and samples in swath
   B. Do this for data for HGS, MGS and LGS
   C. Flag and filter out saturated data, and data close to zero counts
2. Separate samples into Aggregation Modes (aggMd)
3. Perform a zero-constrained linear fit
   A. Do for each aggMd, detector and gain stage
   B. Slope of fit is the gain, $L/dn = G_{agg,det,stg}$
4. Determine gain ratio from *dn* for for radiance cross-over range.
   A. Cross-over range is where higher gain stage is not saturated and lower gain stage is above a minimum threshold *dn.*
   B. Take the average for all radiance levels in the cross-over range, $R_{agg,det,stg1,stg2} = \text{mean}(dn_{agg,det,stg1,lev}/dn_{agg,det,stg2,lev})$
5. Determine the gain ratio error:
   $E_{agg,det,stg1,stg2} = R_{agg,det,stg1,stg2} \cdot G_{agg,det,stg1}/G_{agg,det,stg2} - 1$

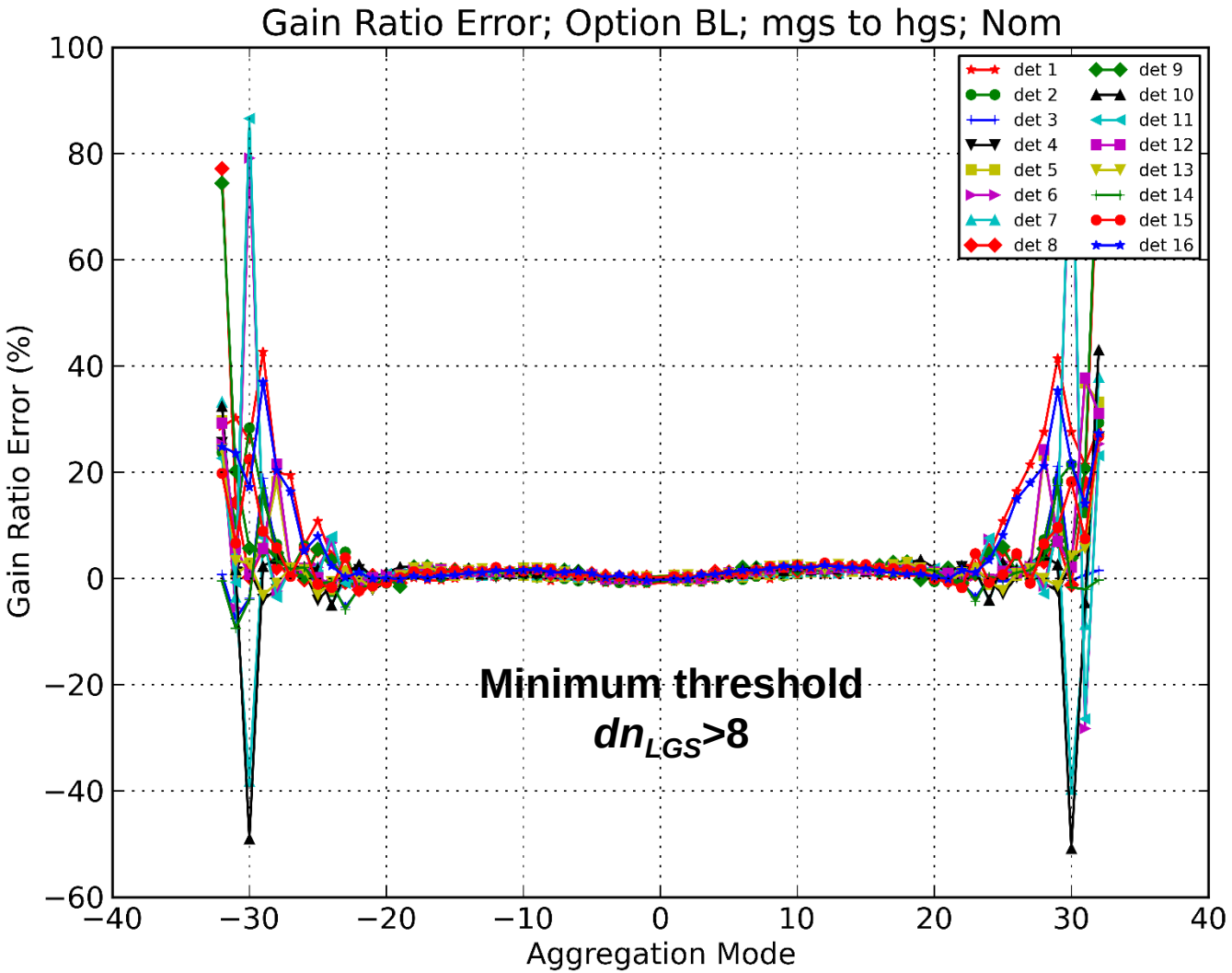
LGS-to-MGS Gain Ratio Errors for Baseline



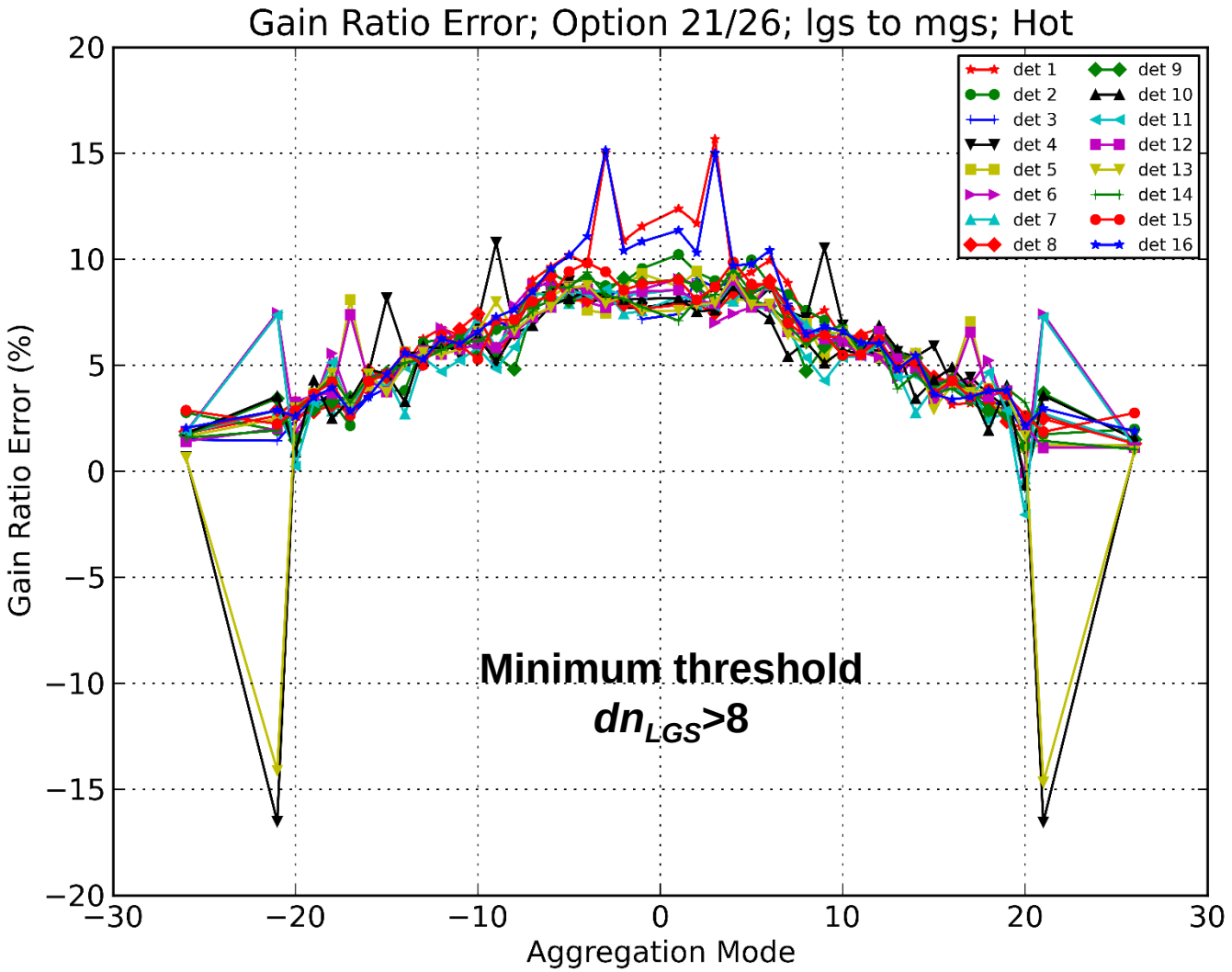
MGS-to-HGS Gain Ratio Errors for Baseline



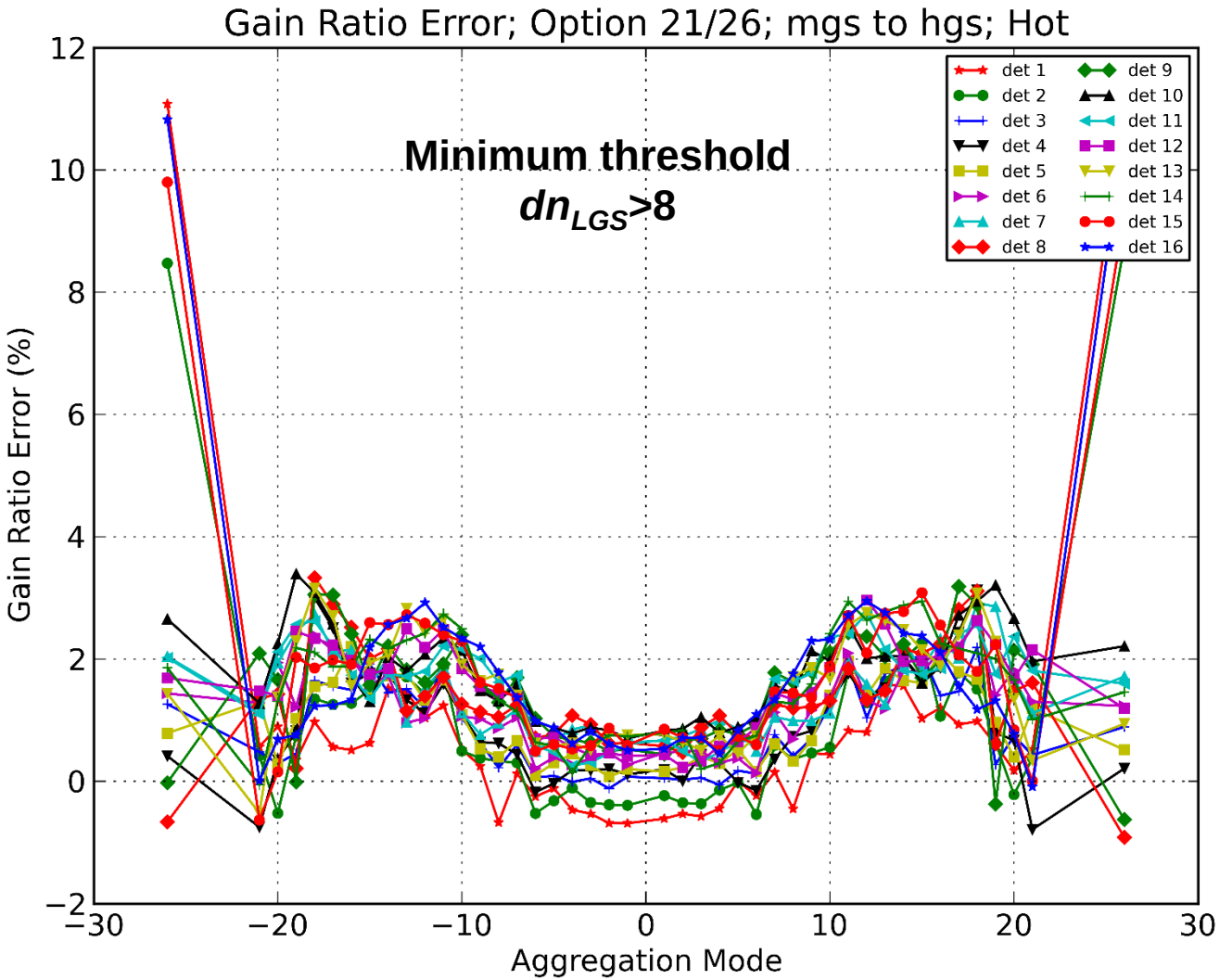
LGS-to-HGS Total Gain Ratio Errors for Baseline



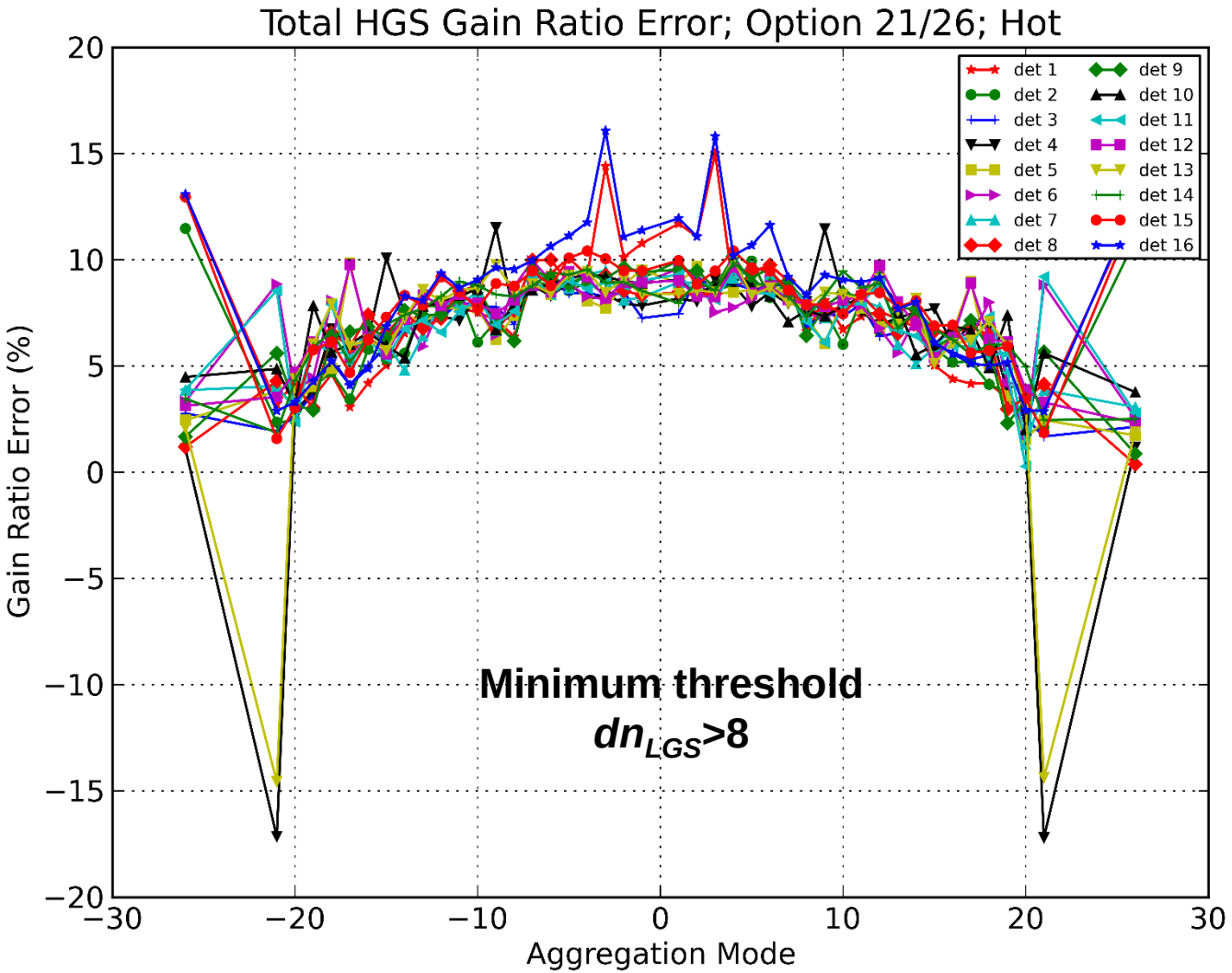
LGS-to-MGS Gain Ratio Errors for Option 26



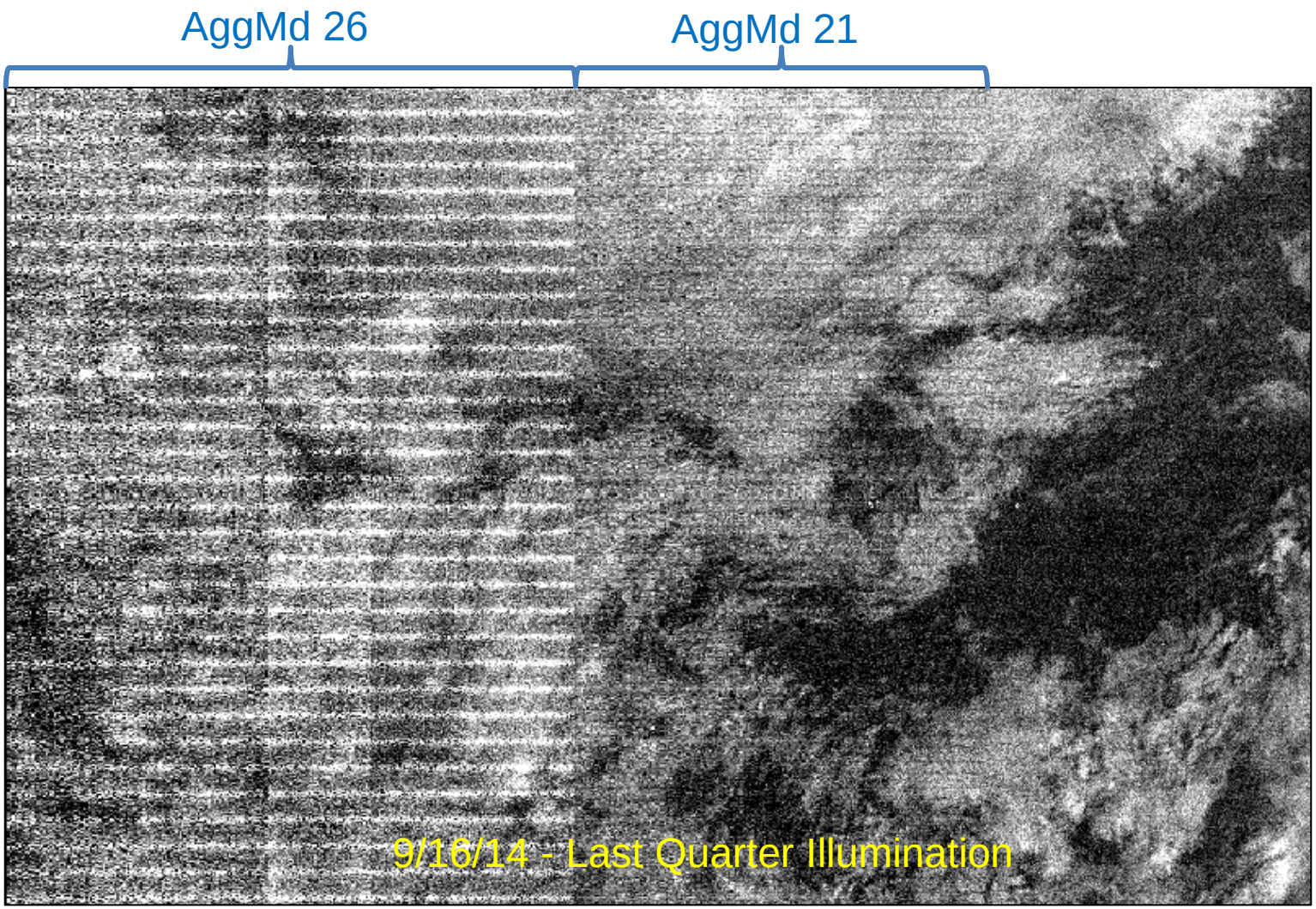
MGS-to-HGS Gain Ratio Errors for Option 26



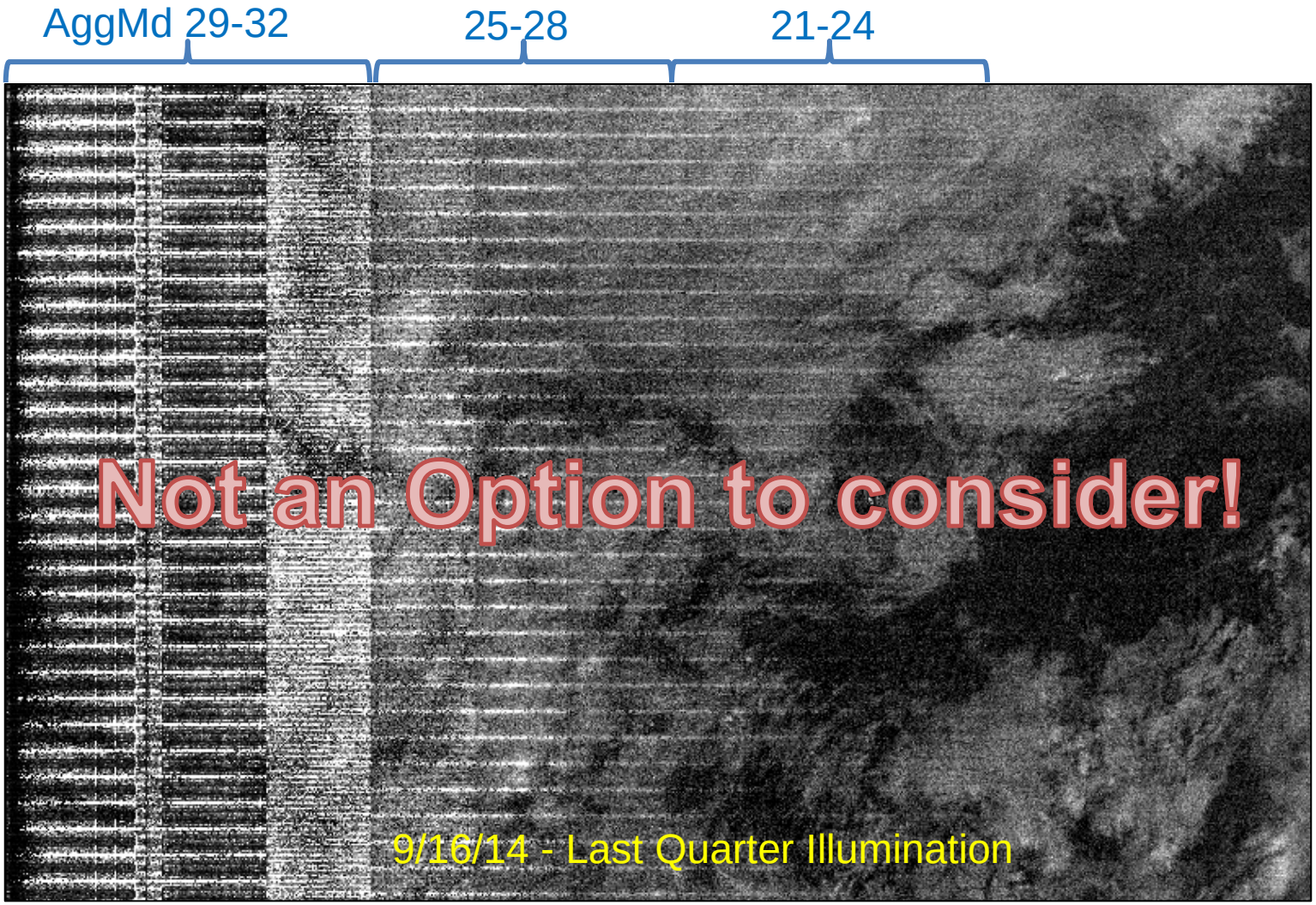
Total LGS-to-HGS Gain Ratio Errors for Option 26



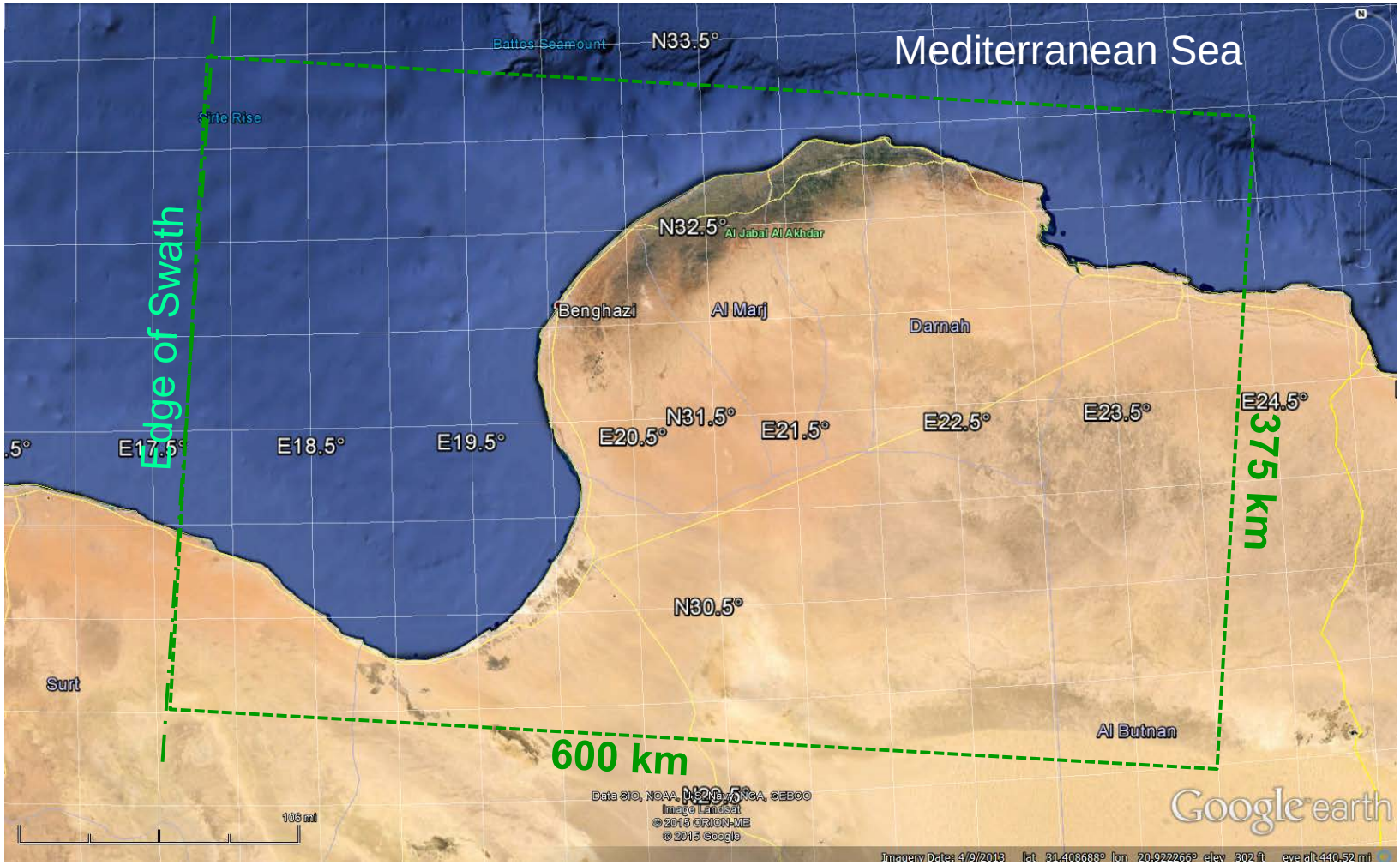
Simulated Option 26



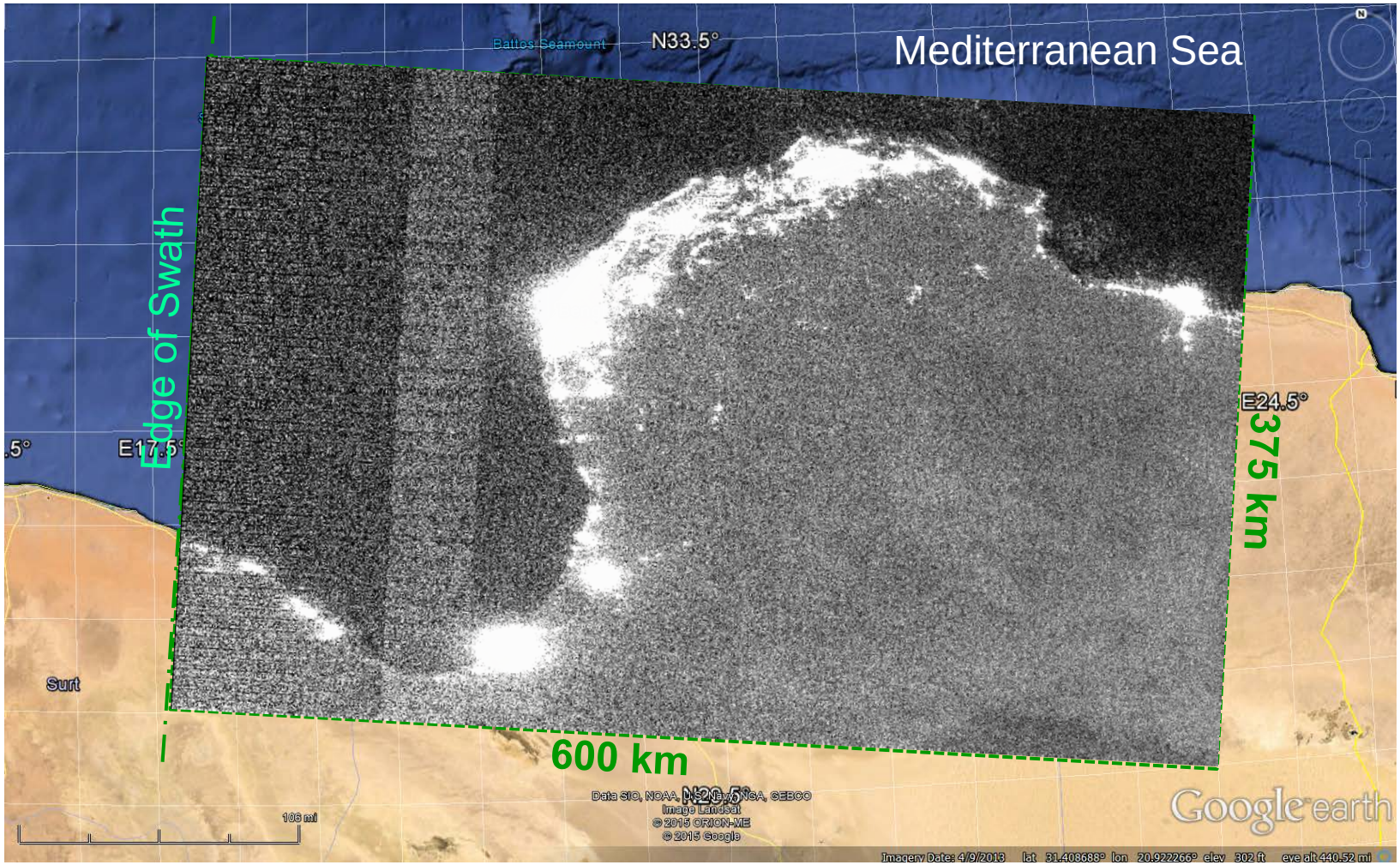
Simulated JPSS-1 Old Baseline



Scene 5-Last Quarter, 9/16/14
Libya & Mediterranean

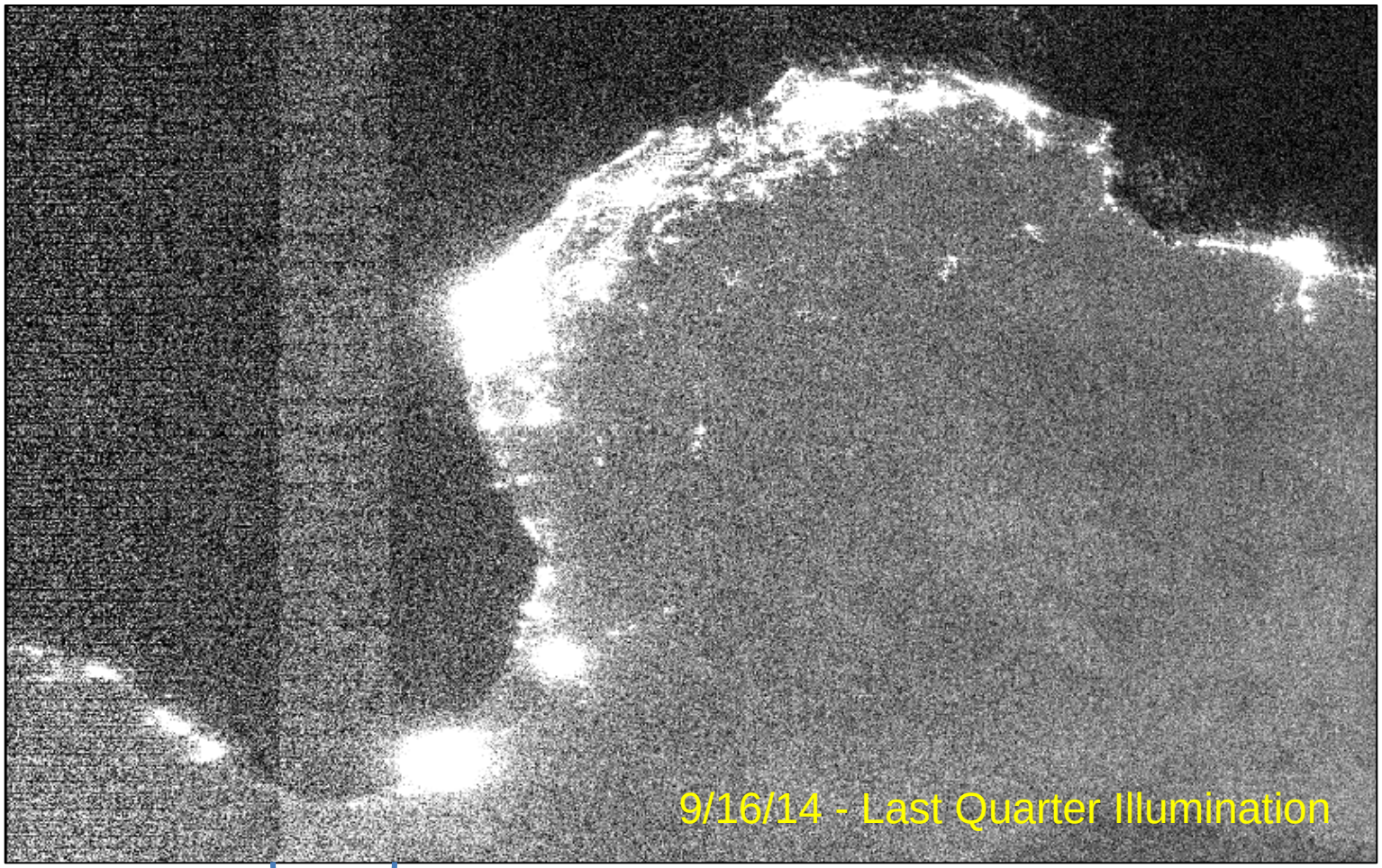


Scene 5-Last Quarter, 9/16/14
Libya & Mediterranean



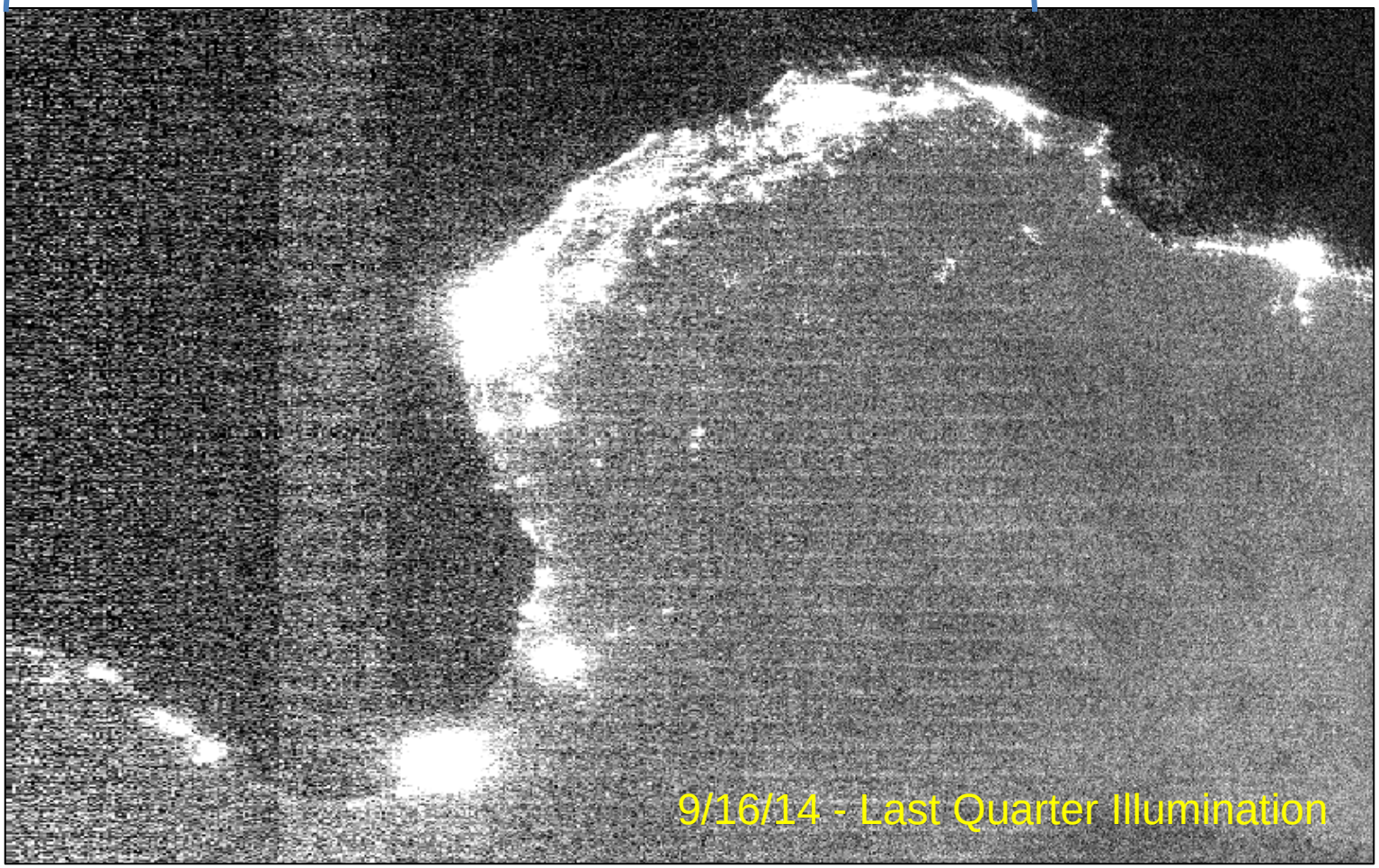
Pristine Edge-of-Swath Image

Radiance range grayscale: black=0.0; white=0.8 nW cm^{-2} str^{-1}

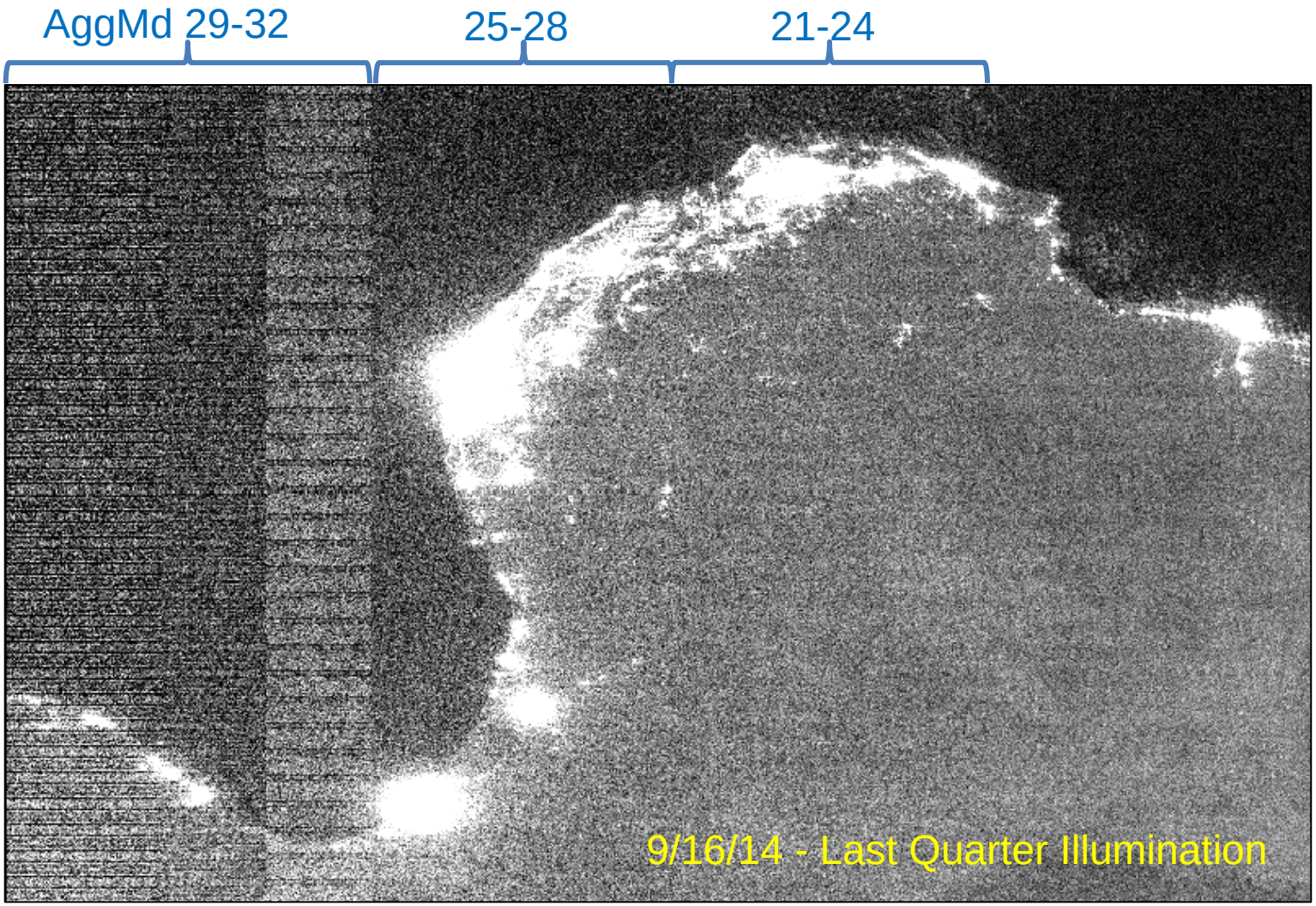


Residual error
after destriping

Simulated JPSS-1, Option 21

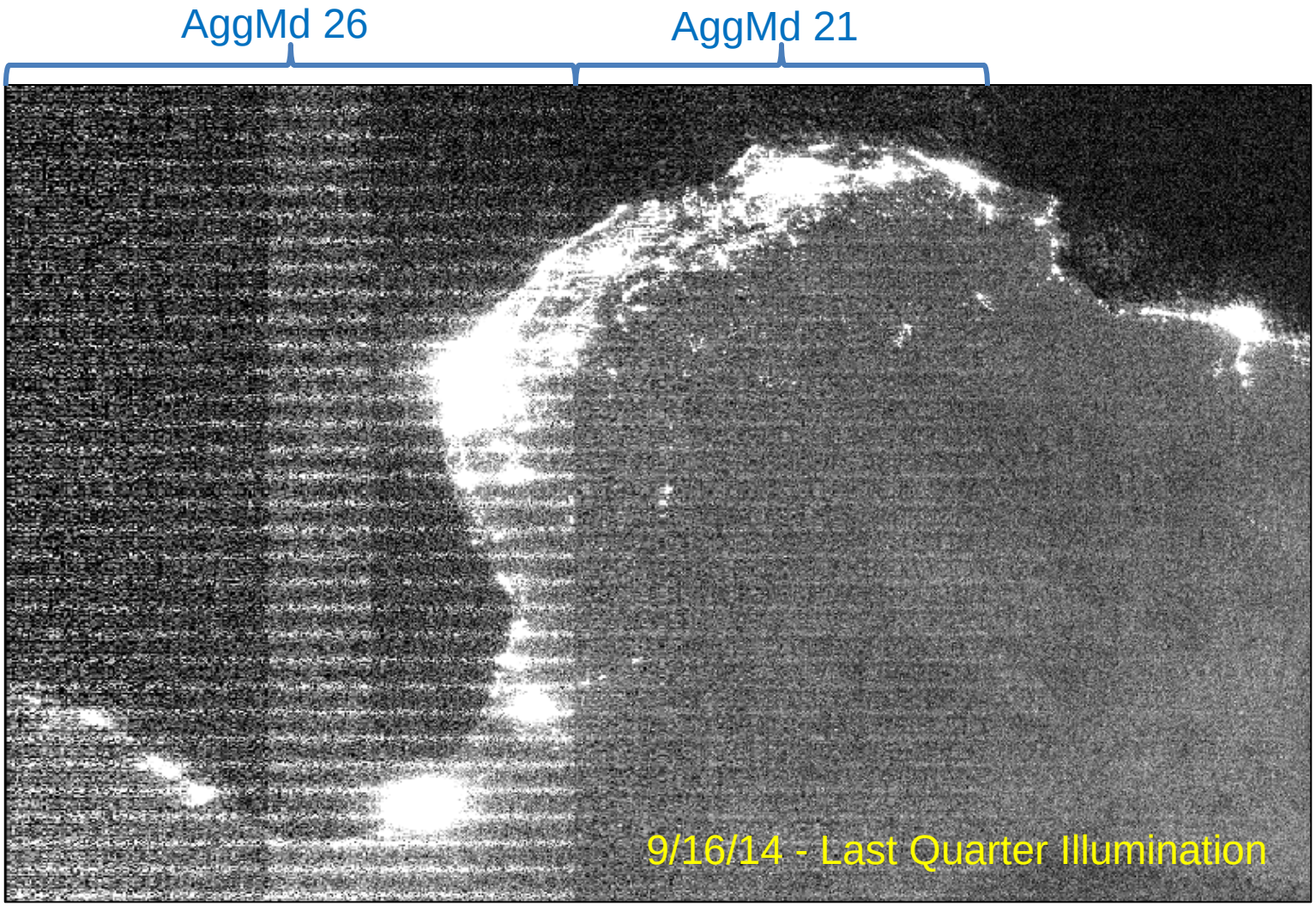


NPP Image with Striping



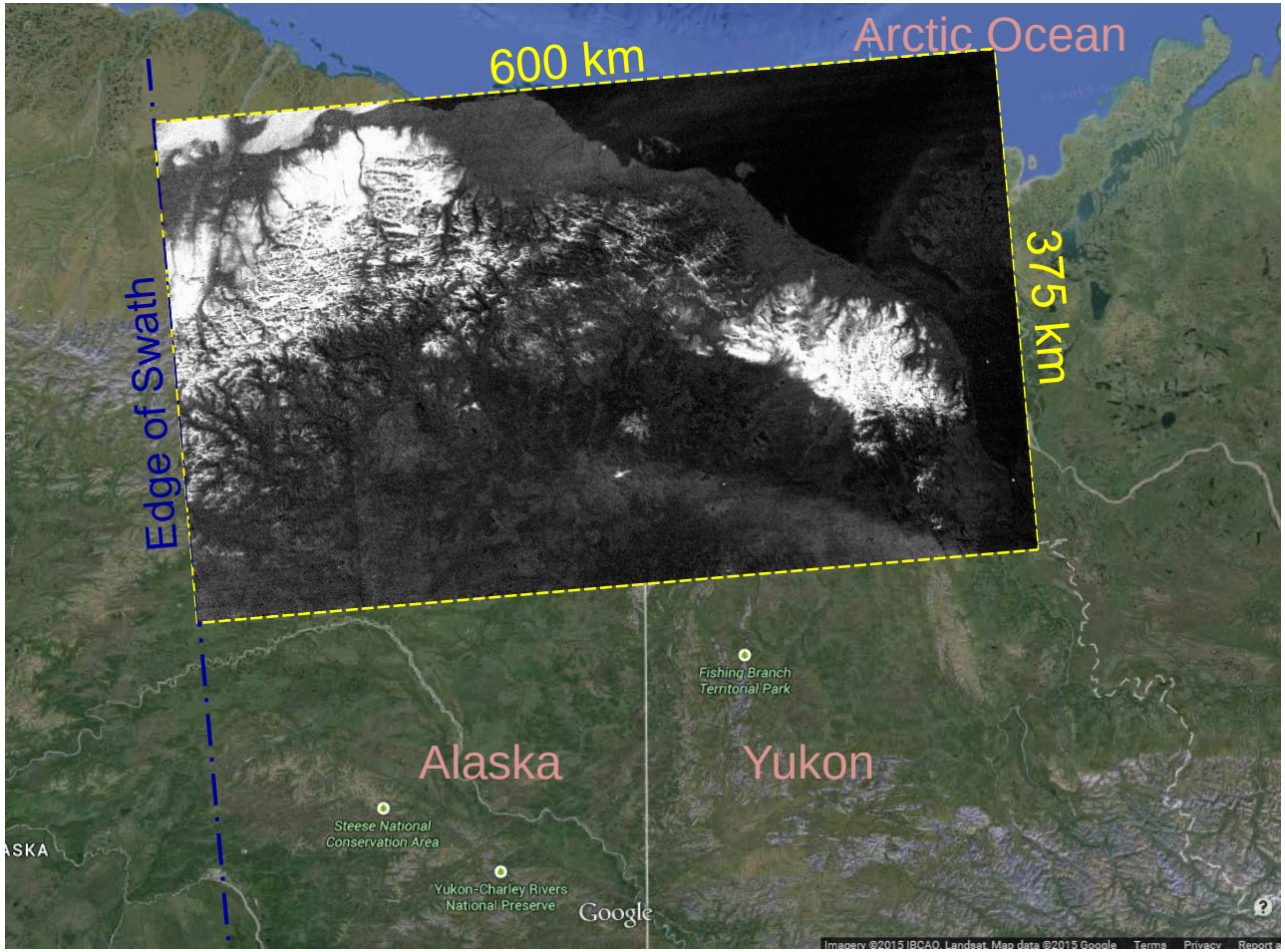
S-NPP has less striping near edge of scan than either JPSS-1 Option

Simulated Option 26

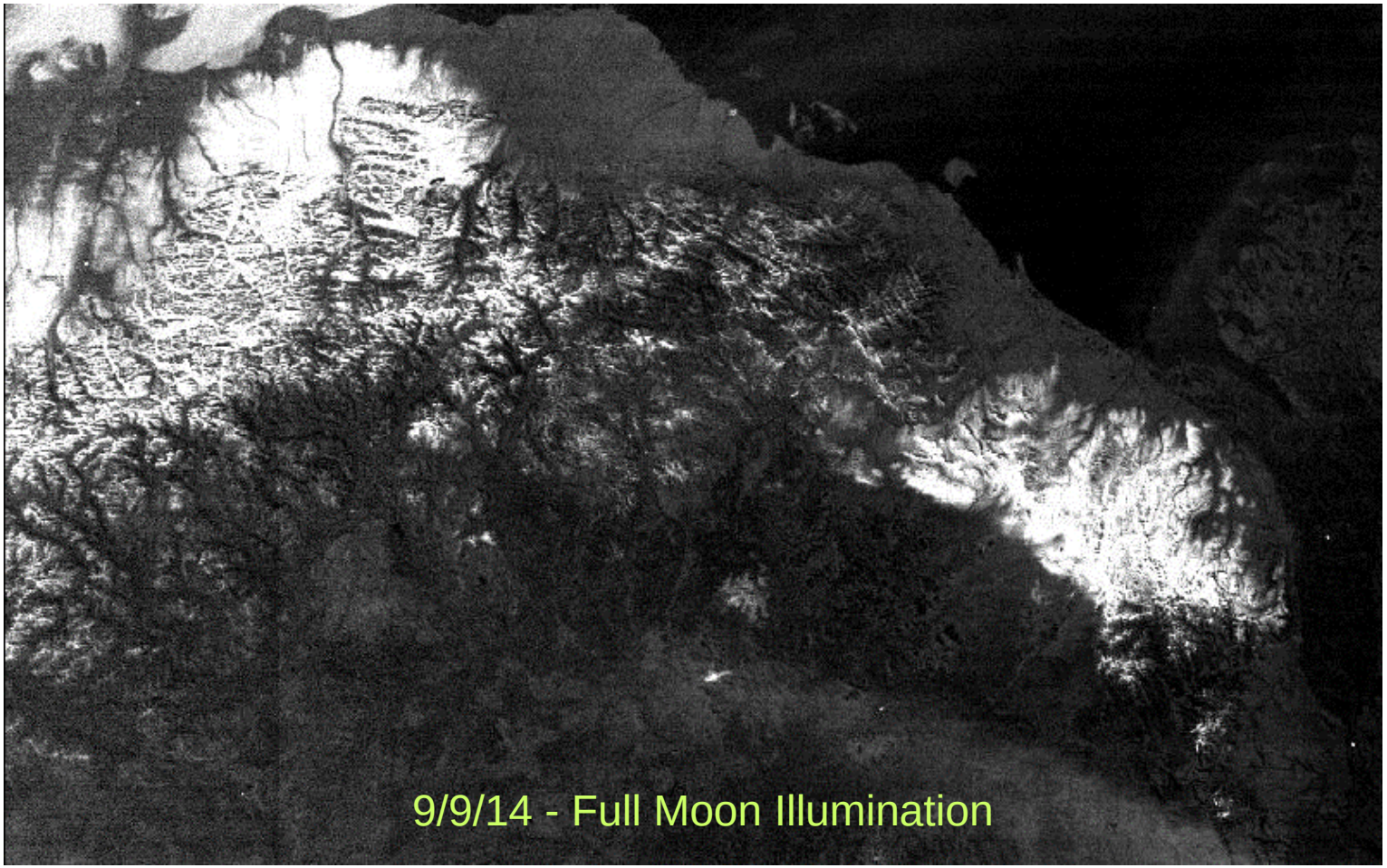


Scene 1, Northern Alaska & Yukon

Scene 1, Northern Alaska & Yukon

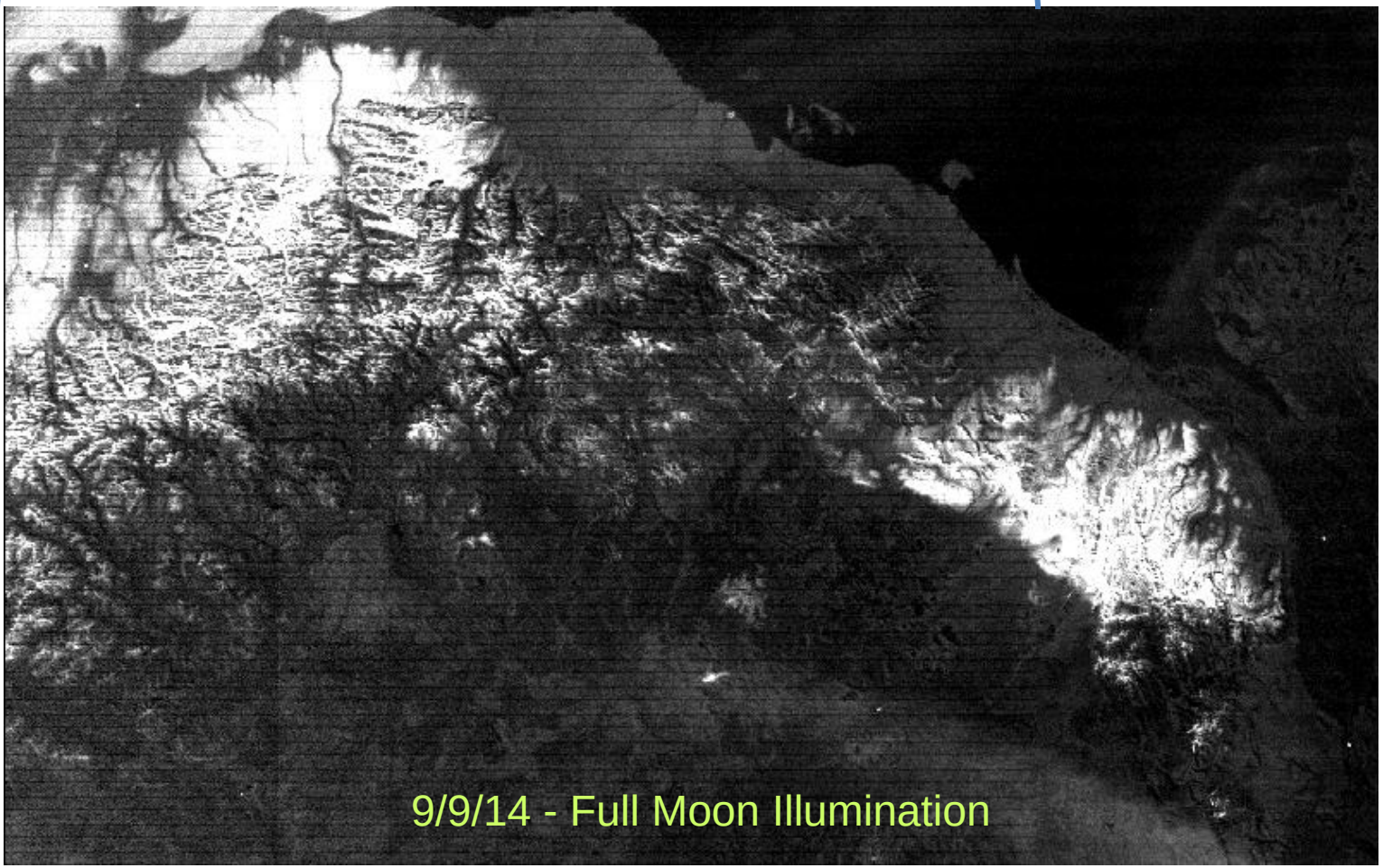


Pristine Edge-of-Swath Image



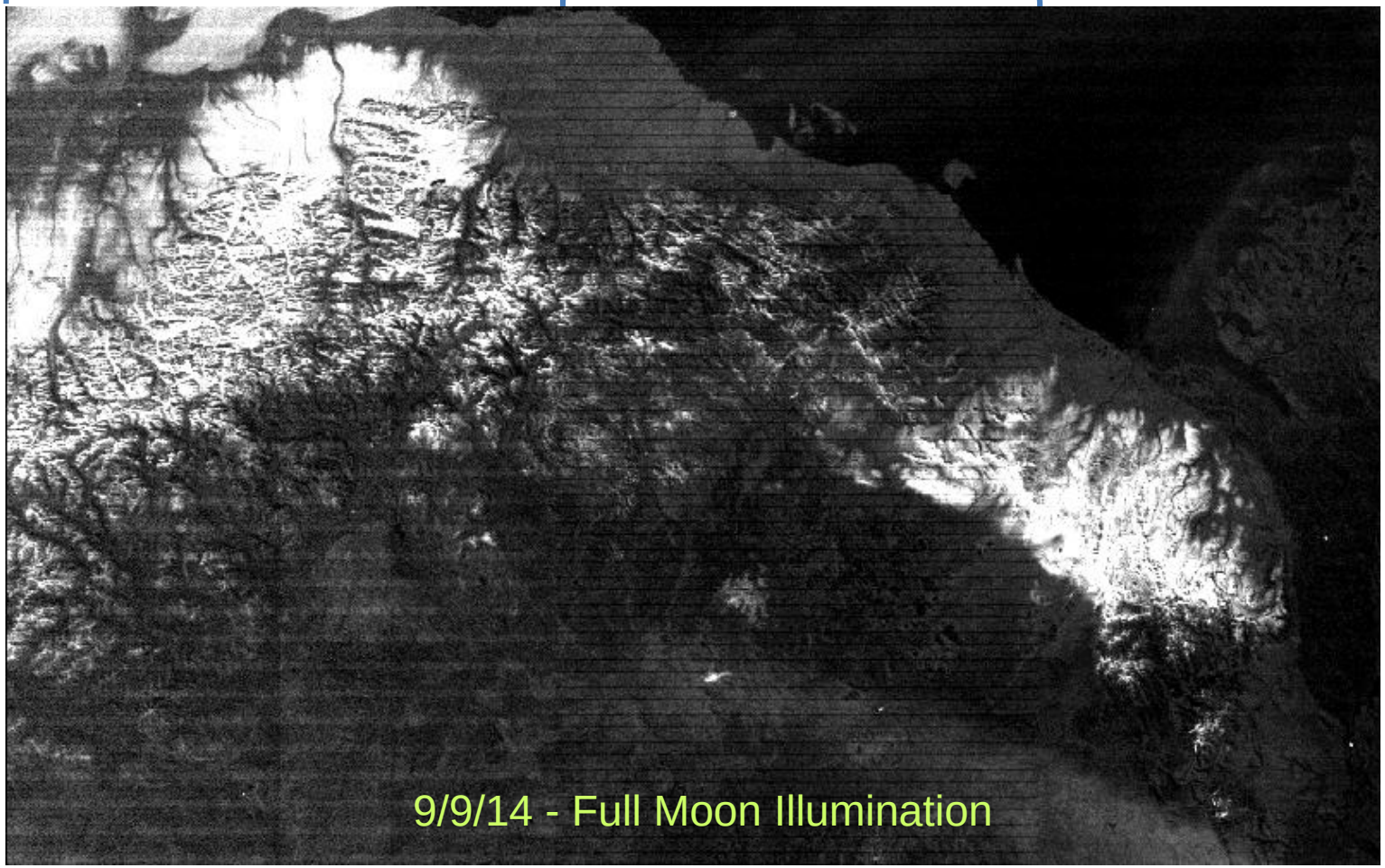
Simulated Option 21

AggMd 21

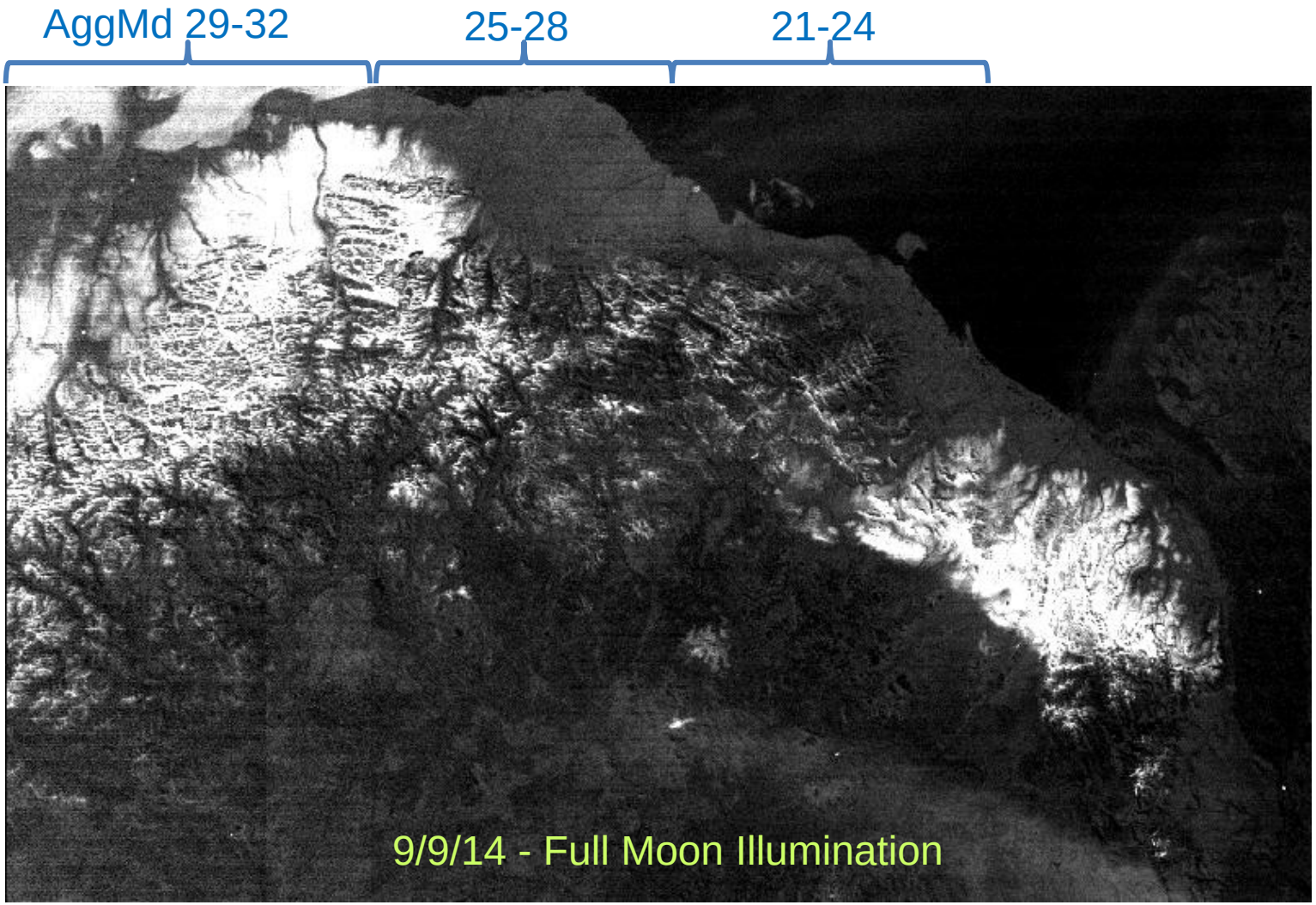


Simulated Option 26

AggMd 26 AggMd 21

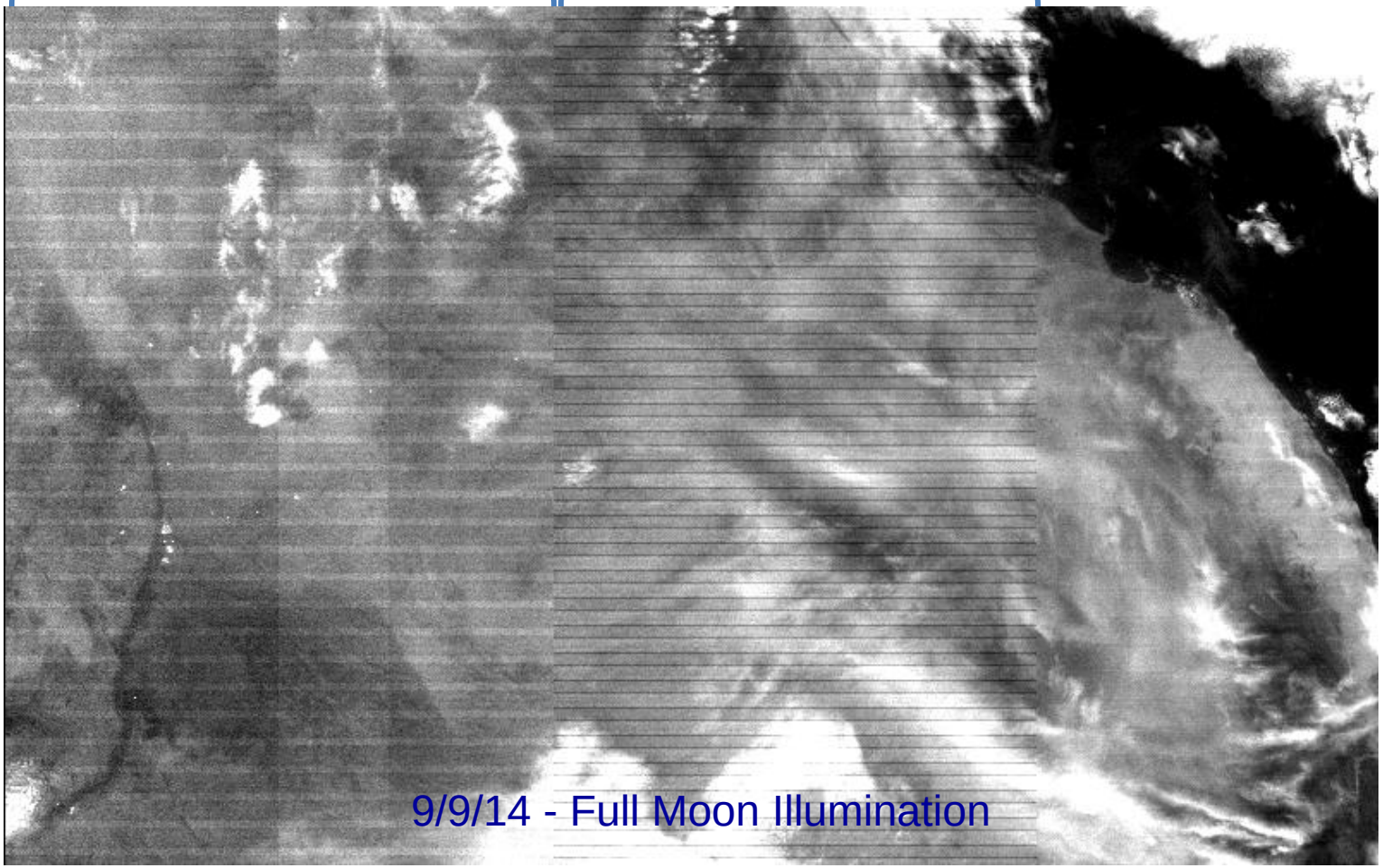


S-NPP Image with Striping

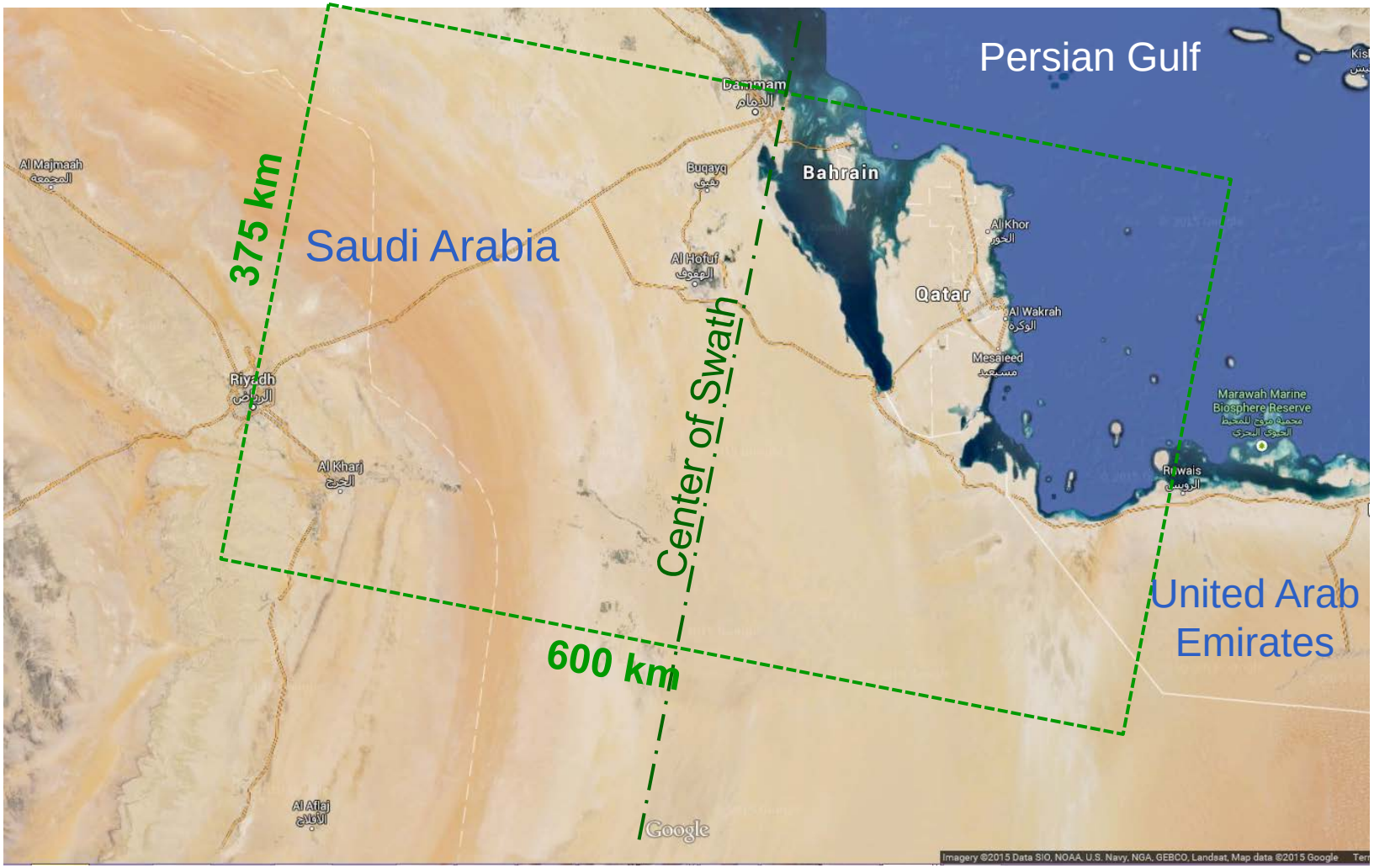


S-NPP has less striping near edge of scan than JPSS-1

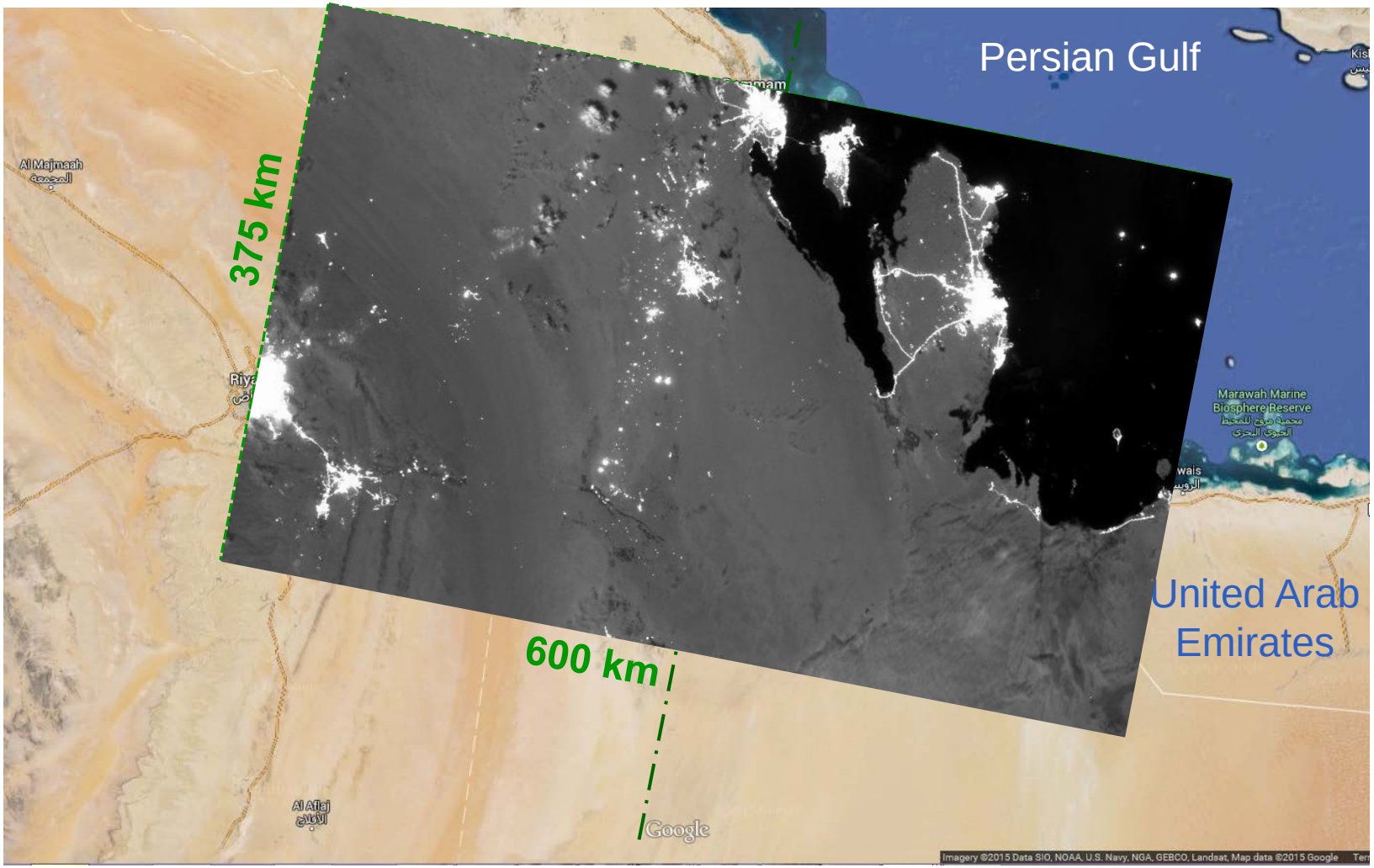
Simulated Option 26



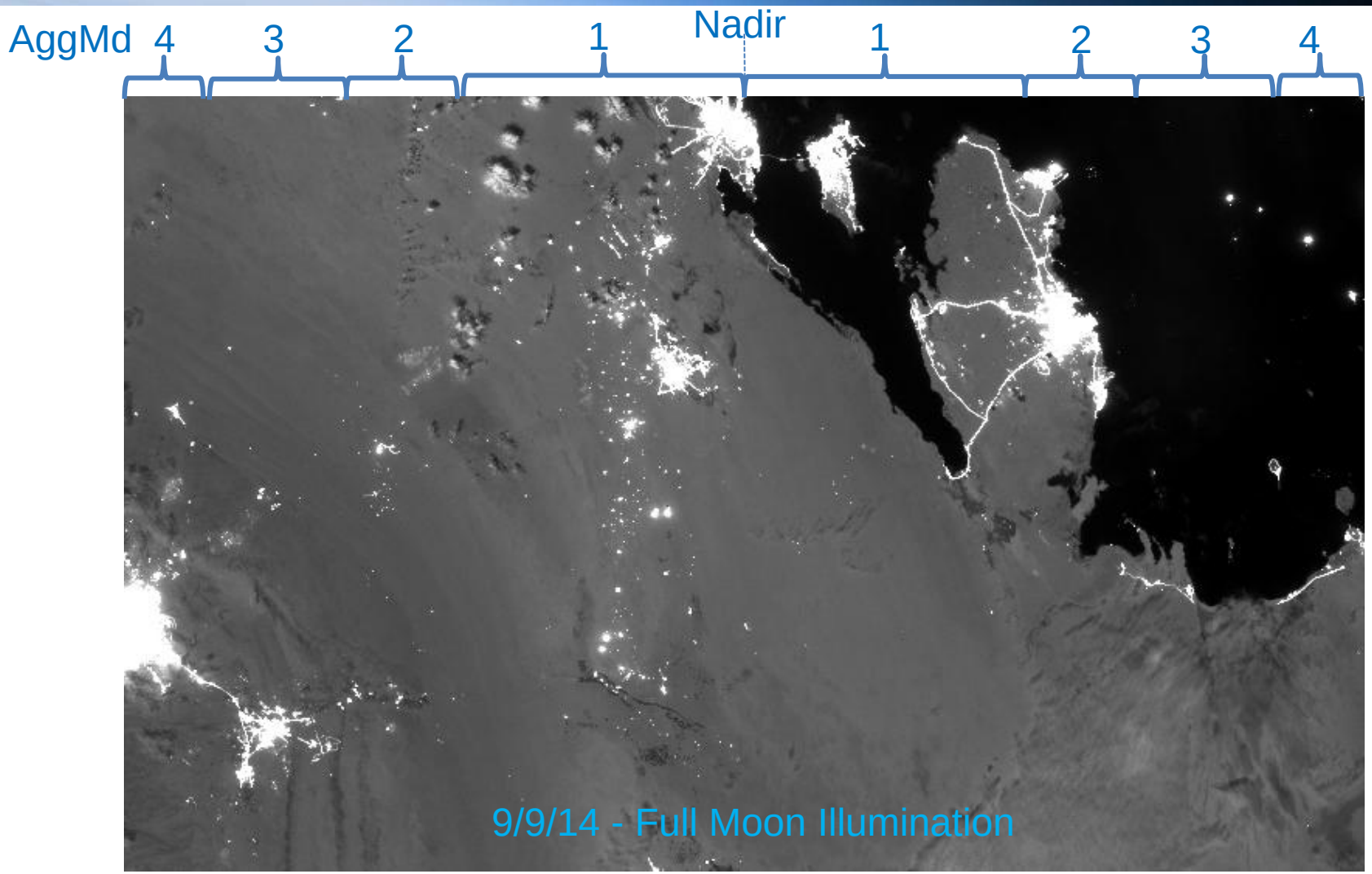
Scene 3, Arabia & Persian Gulf



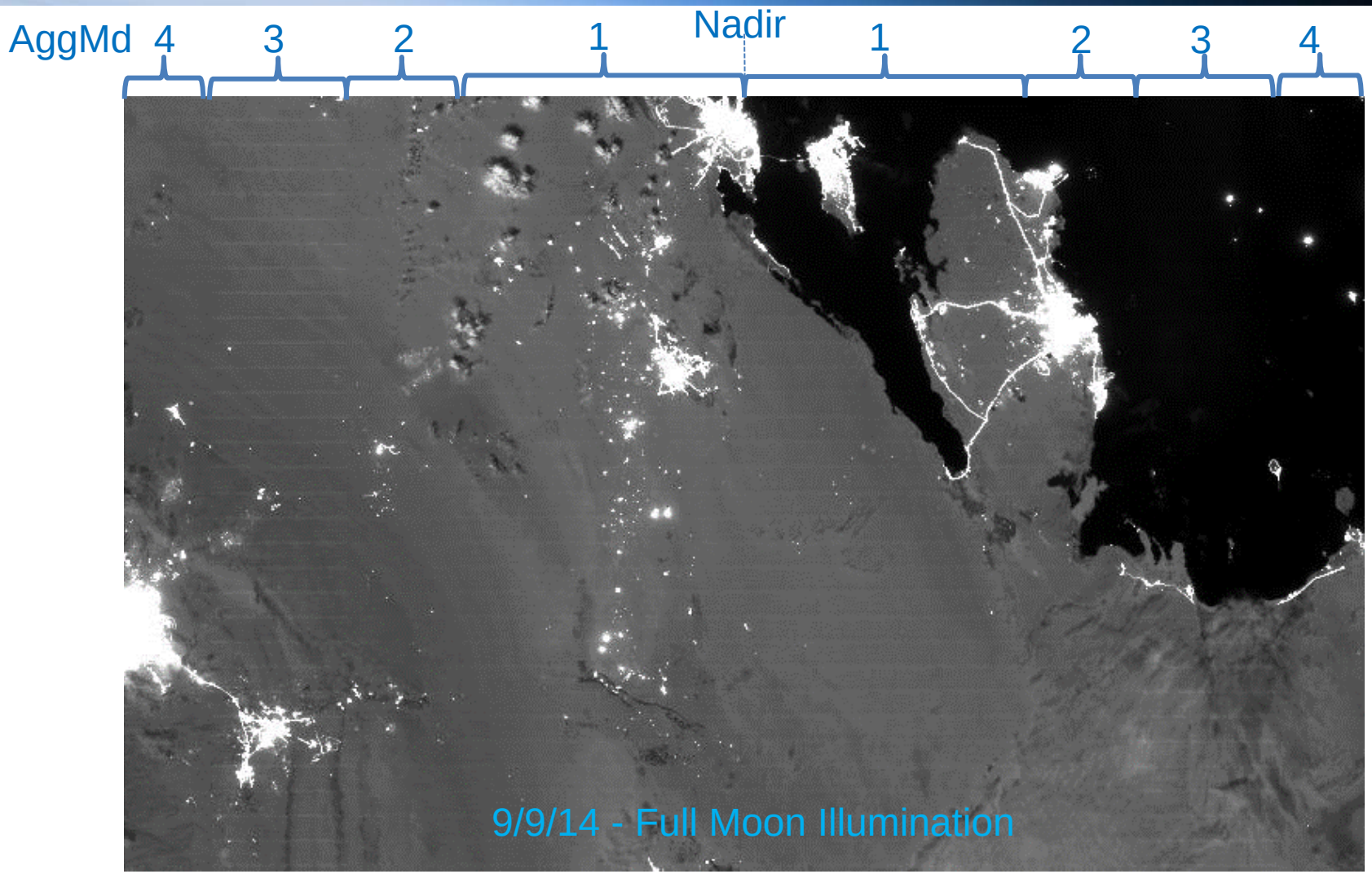
Scene 3, Arabia & Persian Gulf



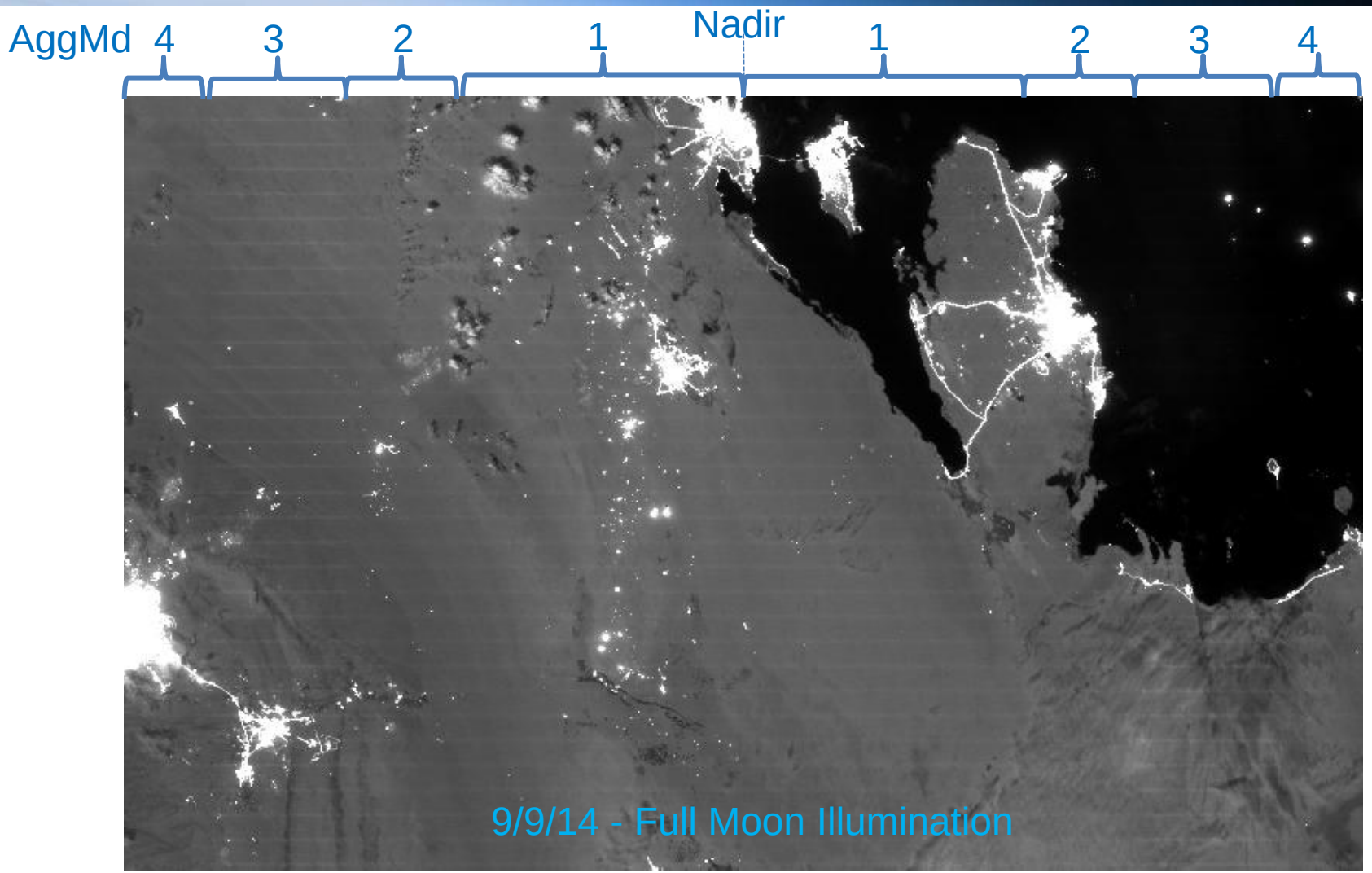
Pristine Nadir Image



Simulated Option 21 or 21/26



S-NPP Image with Striping



S-NPP has similar striping near nadir as JPSS-1

Additional Gain Ratio Error Observations

- Most gain errors are positive, which will cause a negative bias in radiances of MGS and HGS
  - Bias is averages about 8% at nadir
  - Bias decreases to about 2% near edge of scan
  - This is due to higher detector gain in LGS for radiance < 1×10^{-4} W cm^{-2} str^{-1}
- AggMd 26 has 4 detectors that are bad actors in the LGS-to-MGS gain ratio
  - Det. 1, 2, 15 & 16 have gain errors that are about 10% > than most of the others
- AggMds 27 to 32 have large errors in both LGS-to-MGS and MGS-to-HGS gain ratios
  - Errors range from -50% to +85% for AggMd 30
  - These large errors are another reason that the baseline is not a viable option

Simulation Caveats & Assumptions

- Model the reduced pixel resolution in Options 21 or Option 26 only in the scan direction
- Assumes that the same process currently used for the gain ratio computation for S-NPP is **unmodified for JPSS-1**.
  - Assumption based on NOAA STAR presentation 4/9/14
  - NOAA STAR is considering more research and possible update to gain-ratio cross-calibration process after launch
- Does not consider uncertainties in the offset determination.
  - This has been a cause of striping for S-NPP.
- Does not consider the long-term stability of the nonlinearities.
- Because of these assumptions, actual images will likely be worse

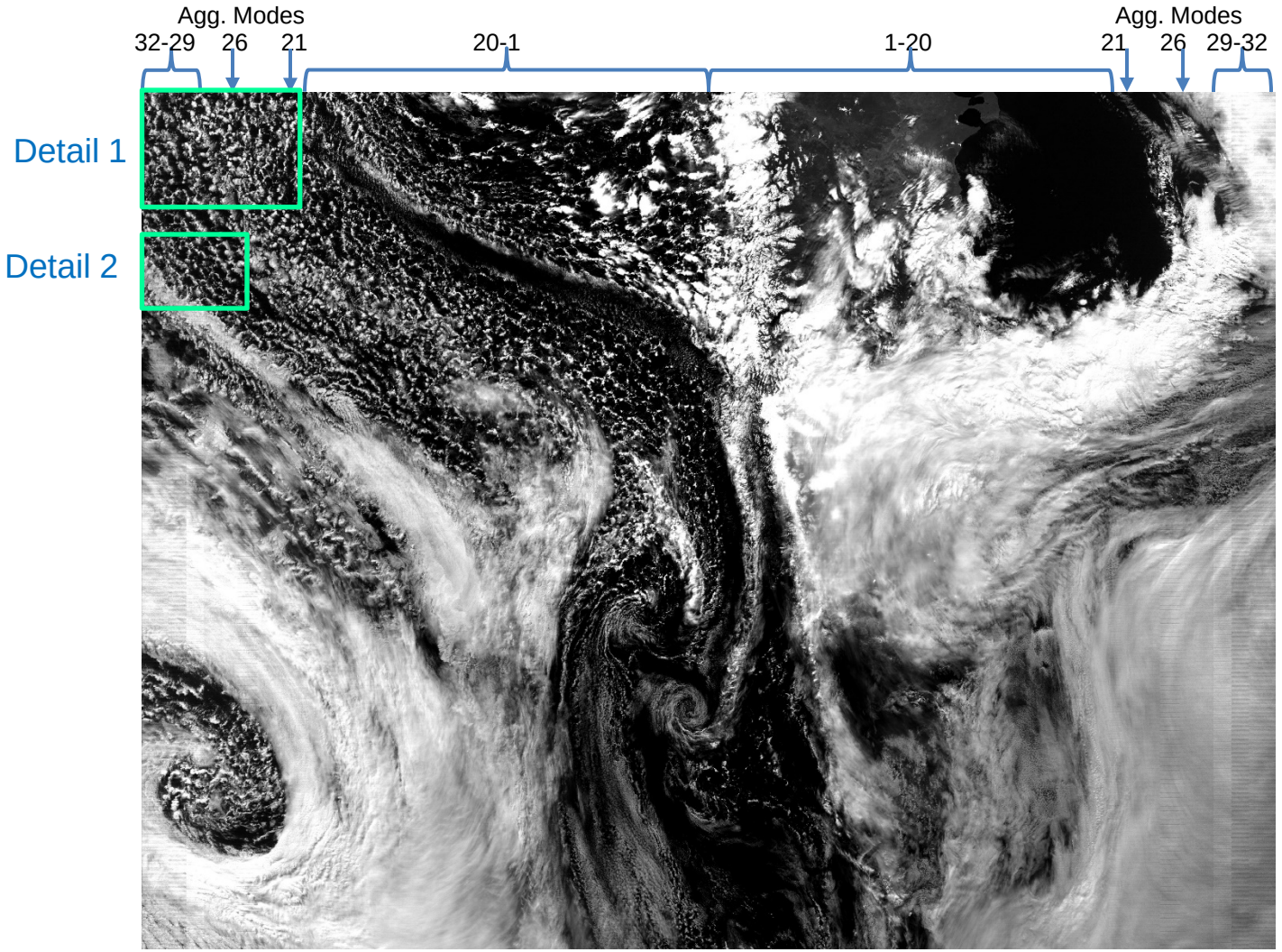
Actual on-orbit striping will almost certainly be worse than shown

Simulated Resolution Affects from reduced Aggregation Modes

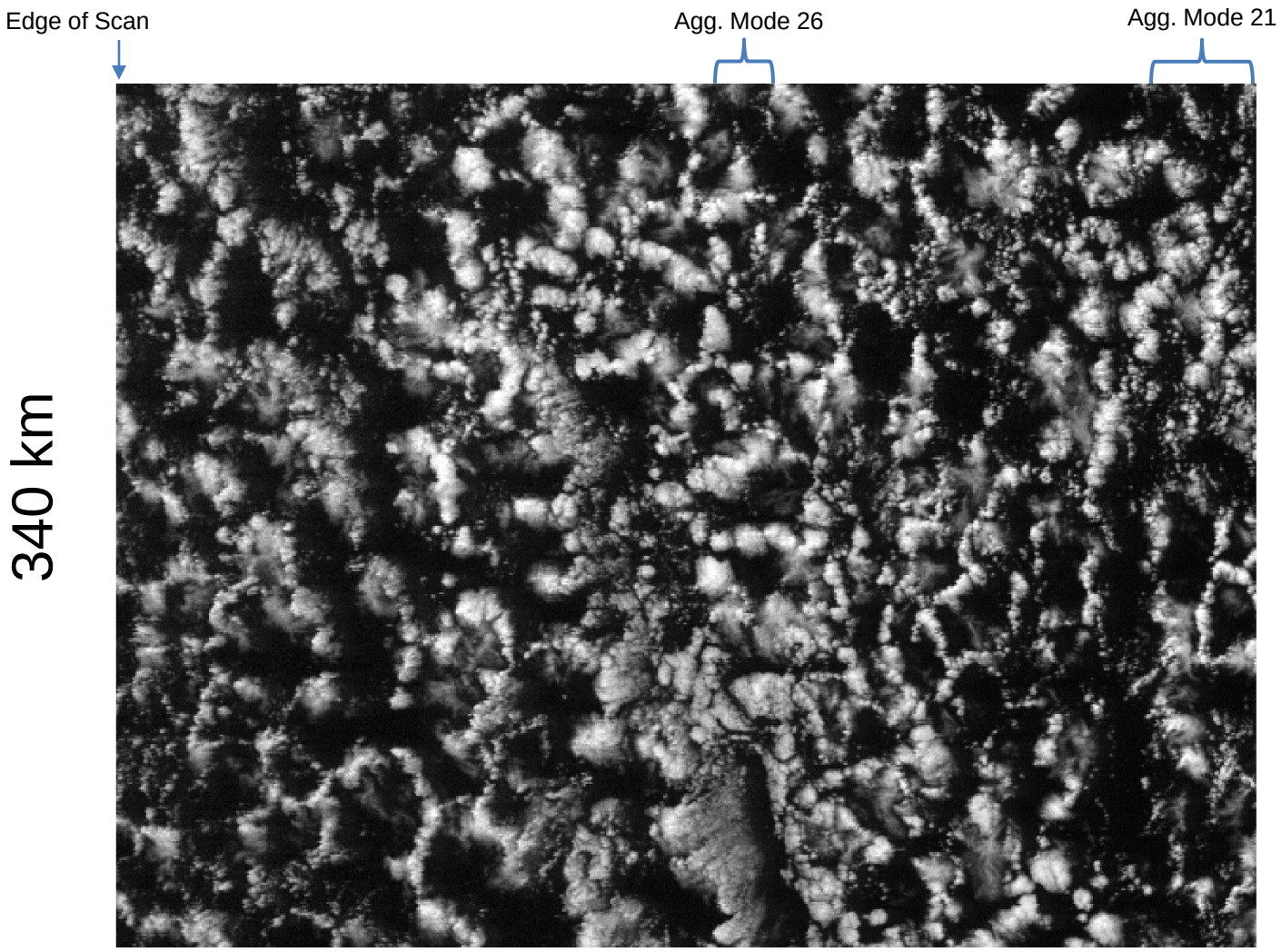
Simulation of spatial resolution

- NPP Scene was chosen to have many small clouds
- NPP striping was removed using destriping algorithm
- Convolutions were performed on each aggregation zone using the size of the cell after aggregation as the kernel
- Scenes are shown for the baseline 750 m cells across the entire swath
- Simulated reduced resolution images are shown for the first 450 km at edge of swath that includes Agg. modes 32- 21
  - Option 21 & Option 26 are simulated
- Images with baseline resolution are compared with the two reduced resolution aggregation options
- Images should be viewed in full screen mode to understand loss of resolution

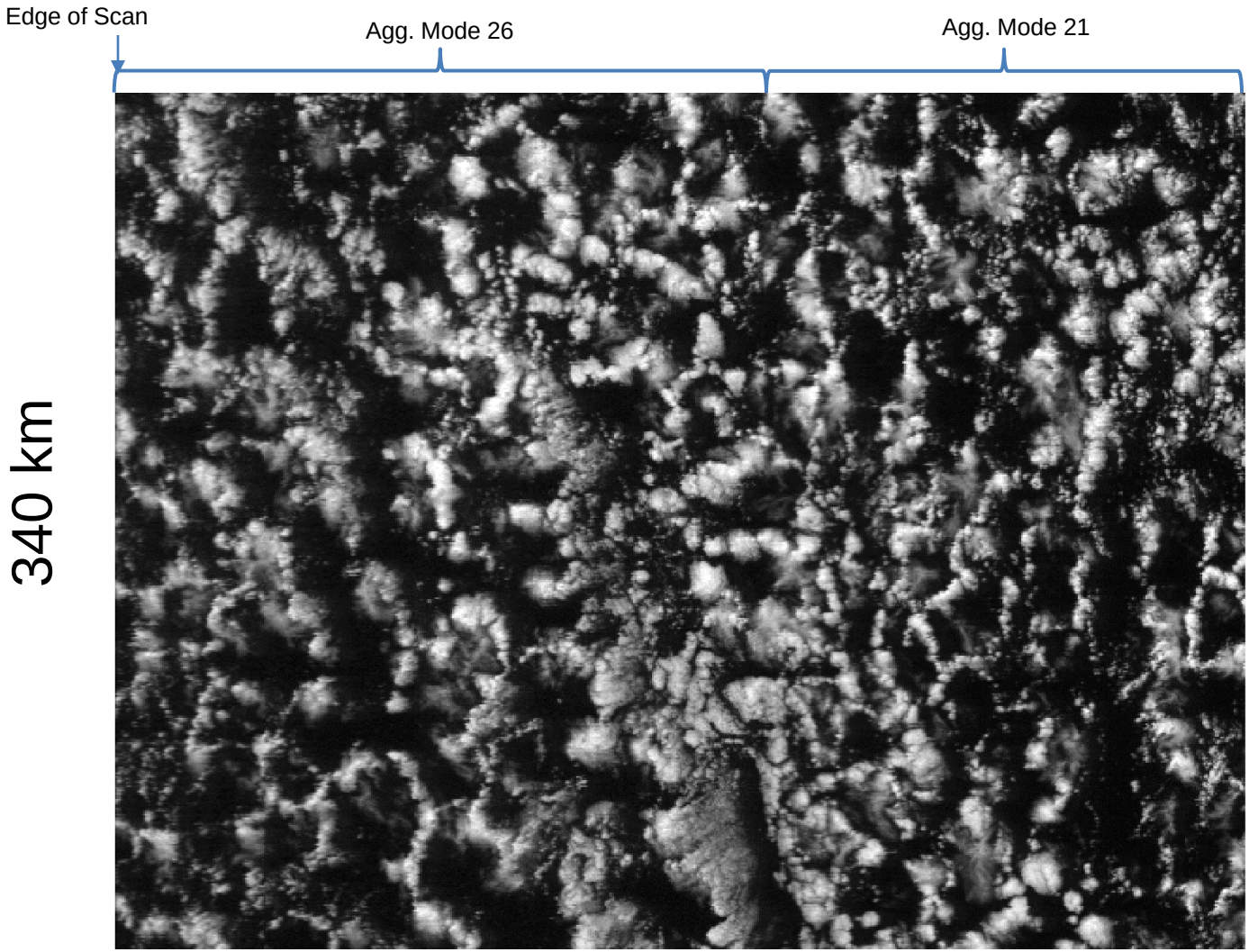
Resolution Test Scene



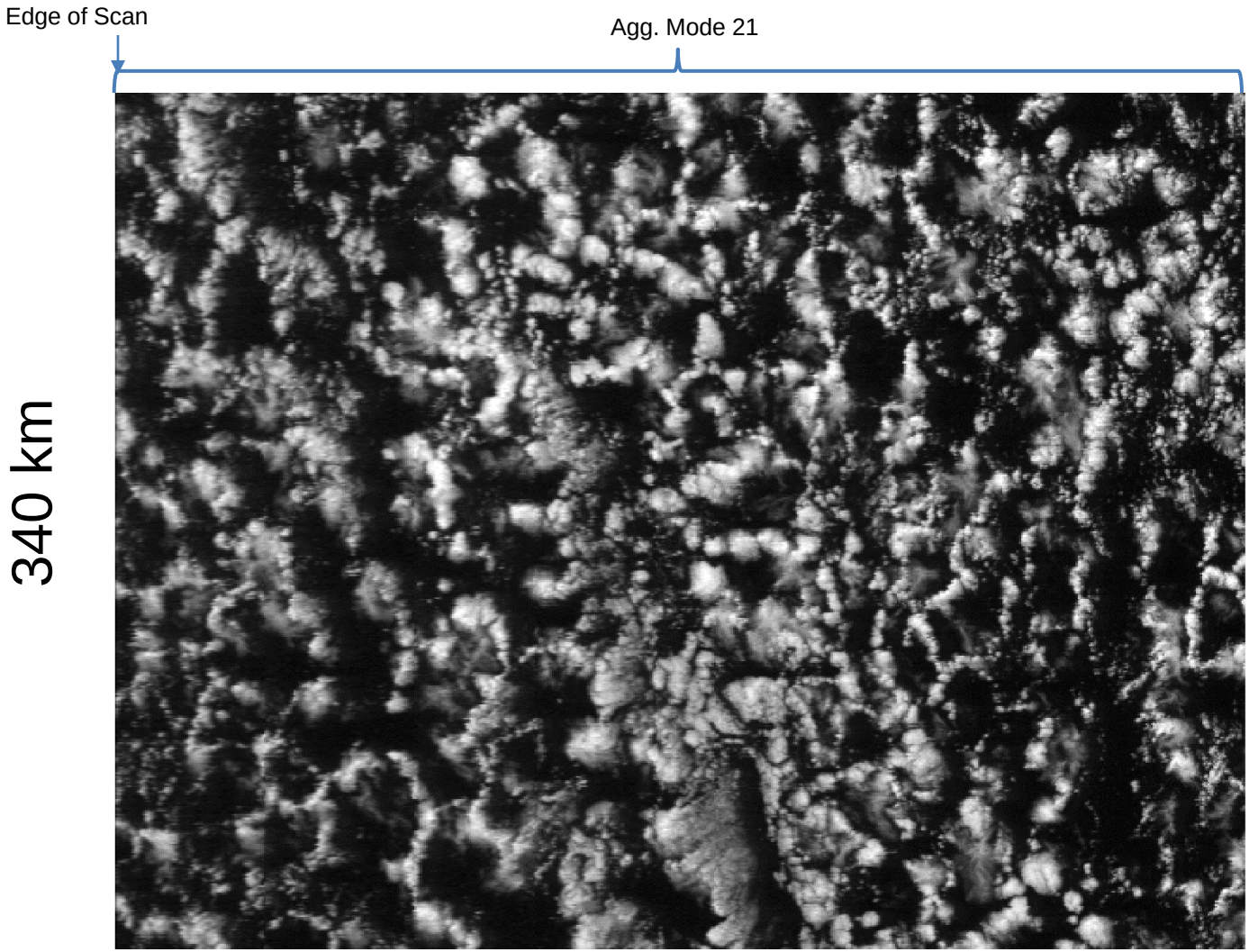
Detail 1, full 750 m resolution



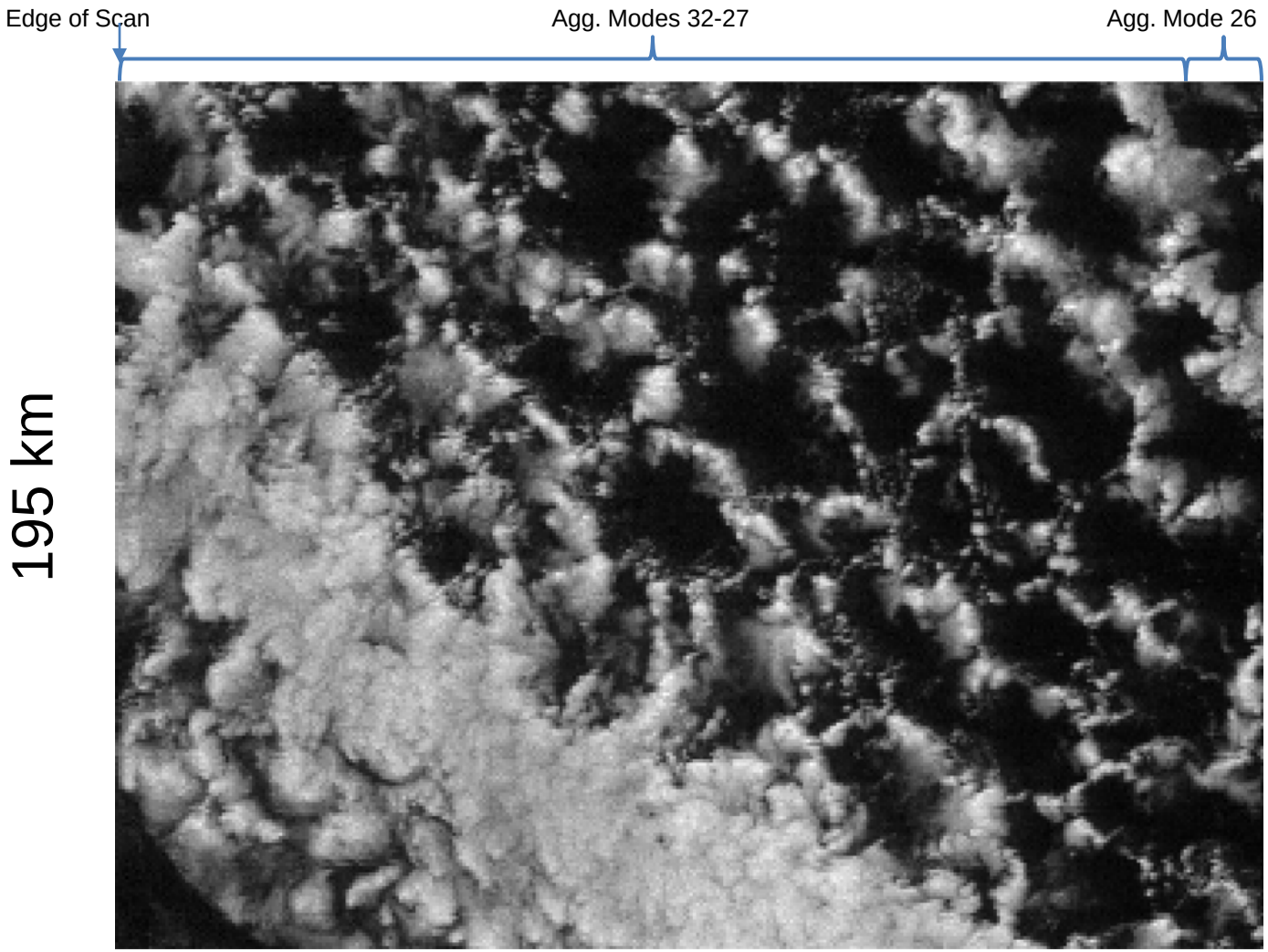
Detail 1, Option 26 resolution



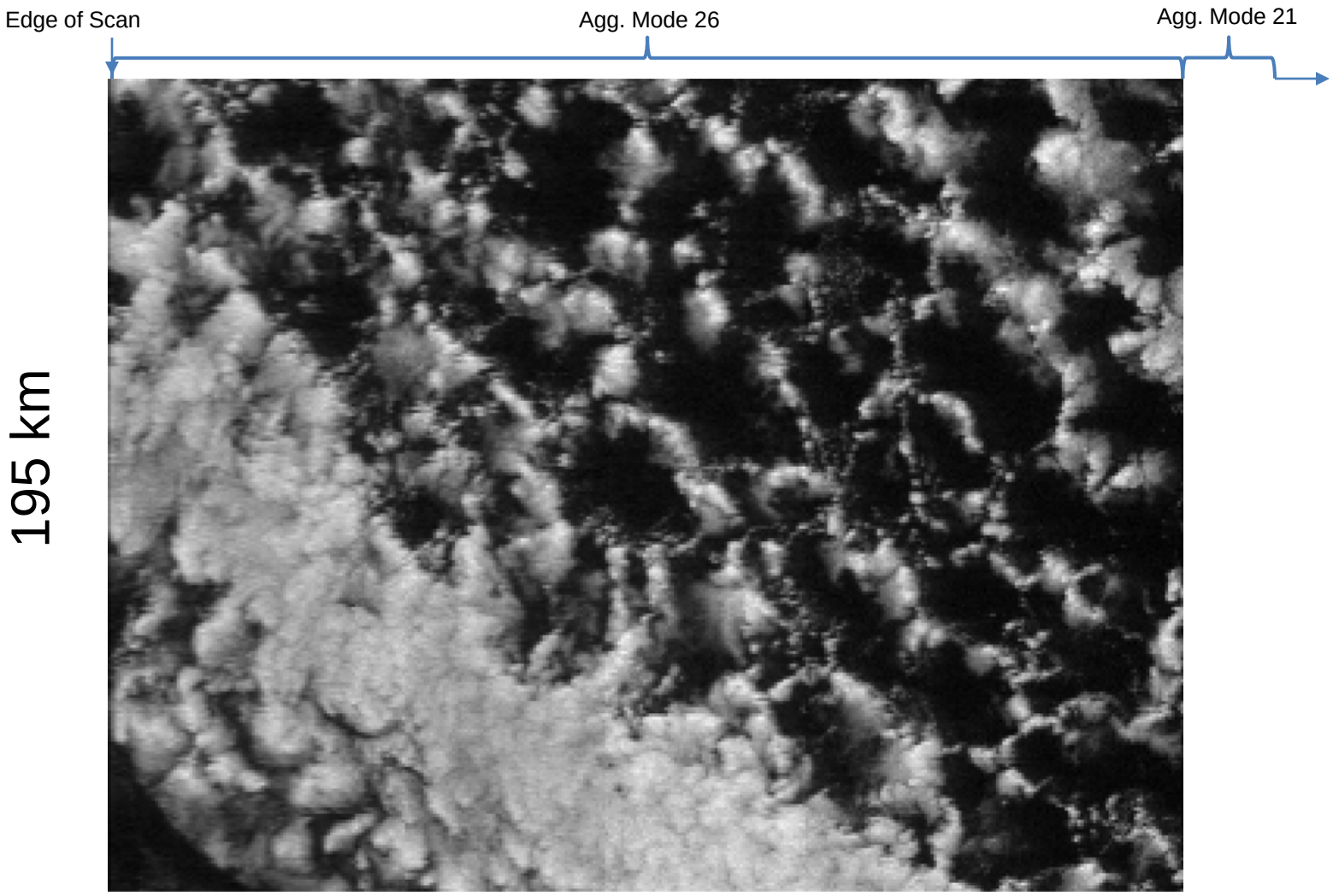
Detail 1, Option 21 resolution



Detail 2, full 750 m resolution



Detail 2, Option 26 resolution



Detail 2, Option 21 resolution