

# **MODIS File Formats**

# MODIS Level 1B File Format

Level 1B contains geolocated calibrated reflectances in 5-minute scenes known as granules.

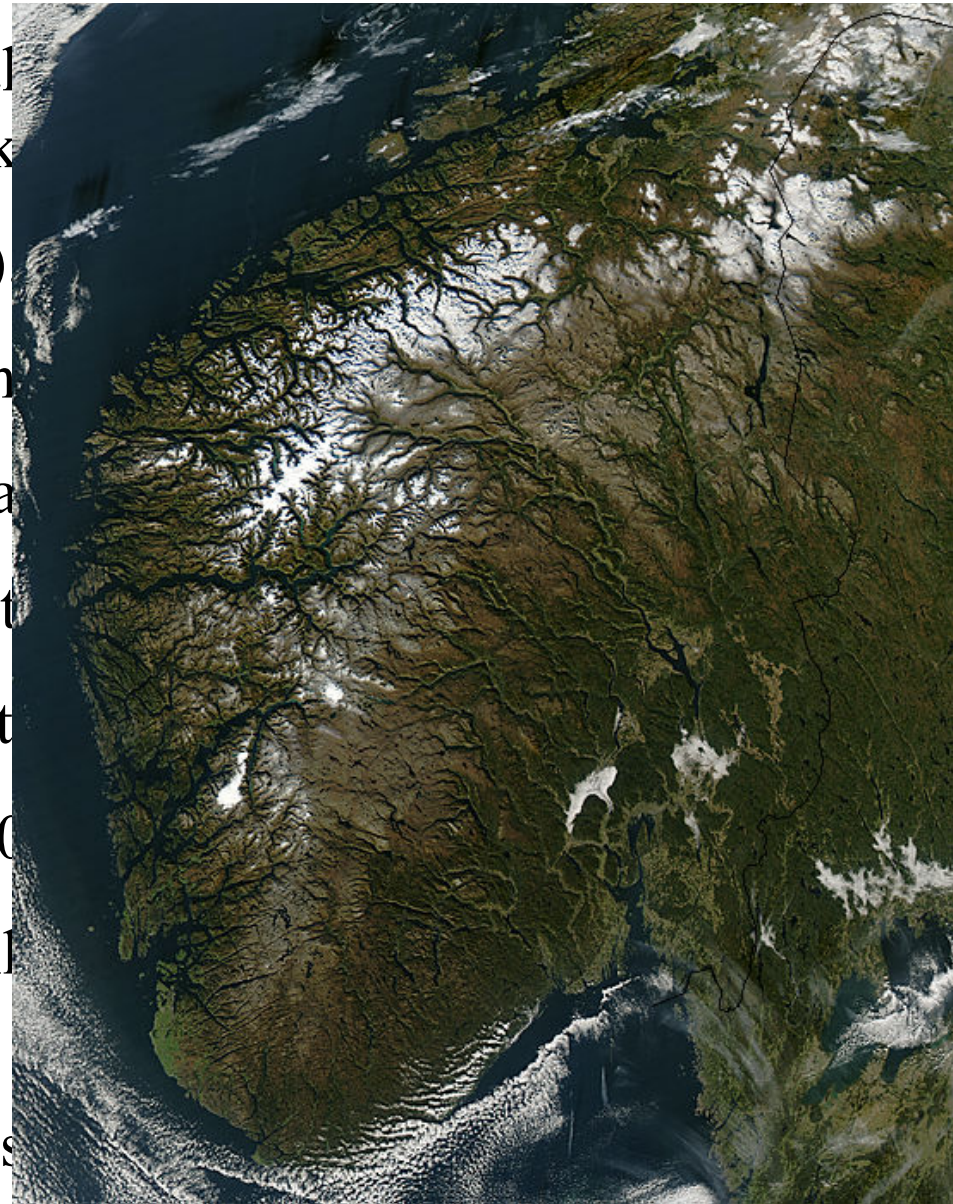
File format is HDF4 (not HDF5).

MODIS is split into four different products:

- MOD021KM (bands 1-36 at 1 km resolution)
- MOD02HKM (bands 1-7 at 1 km resolution)
- MOD02QKM (bands 1,2 at 1 km resolution)
- MOD03 (geolocation at 100 m resolution)

During night portion of orbit, only thermal bands are saved.

Each file contains metadata in a separate file.





# MODIS Level 2 File Format

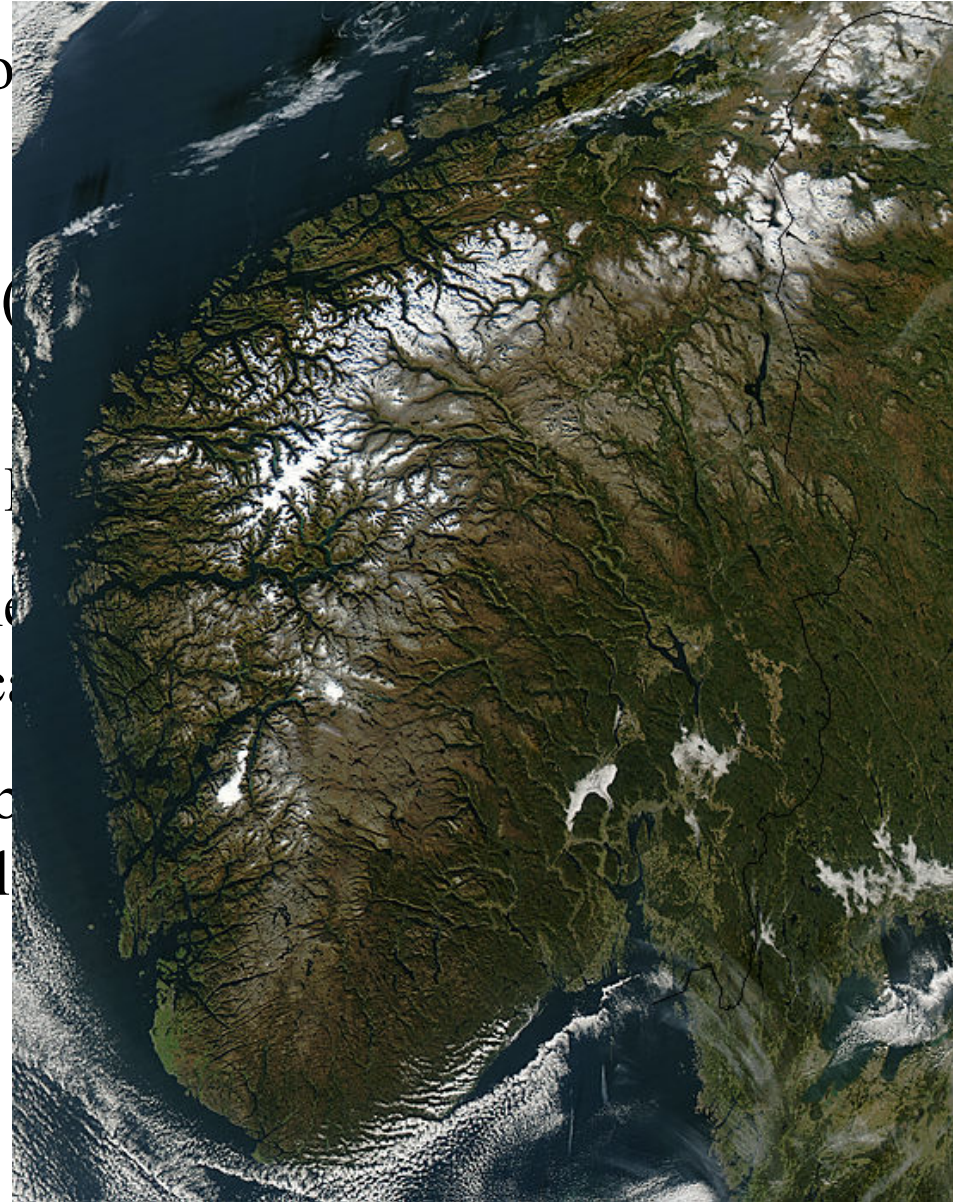
Level 2 contains geophysical products

Two varieties are available:

1. IMAPP format is flat binary (not platform compatible)
2. DAAC format is HDF4 (not platform compatible)

Some Level 2 products are defined at global scale (e.g. cloud mask, cloud optical depth)

Other Level 2 products are at sub-global scale (e.g. snow cover, total precipitable water)



# **Scanner Characteristics**



# MODIS Orbit and Scan Geometry

Terra: 10:30 am local descending

Aqua: 1:30 pm local ascending

Orbit period: 99 minutes

Repeat cycle: 16 days (same as Landsat)

Scan mirror: Double sided, 20.3 revs/minute

Scan rate: 1.477 scans/sec

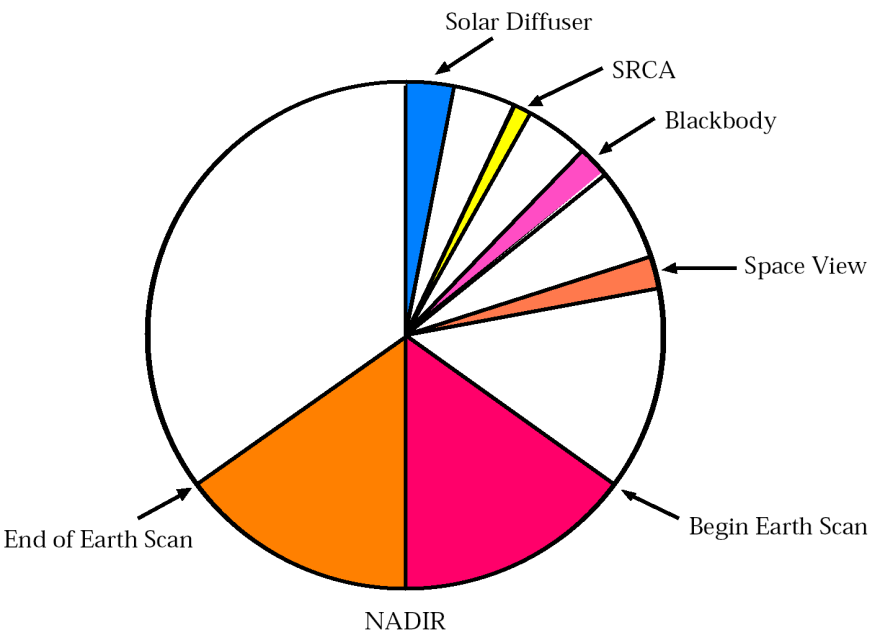
Scan angle: +/- 55 degrees

Swath width: 2330 km across track, 10 km along track

# Image Acquisition Details

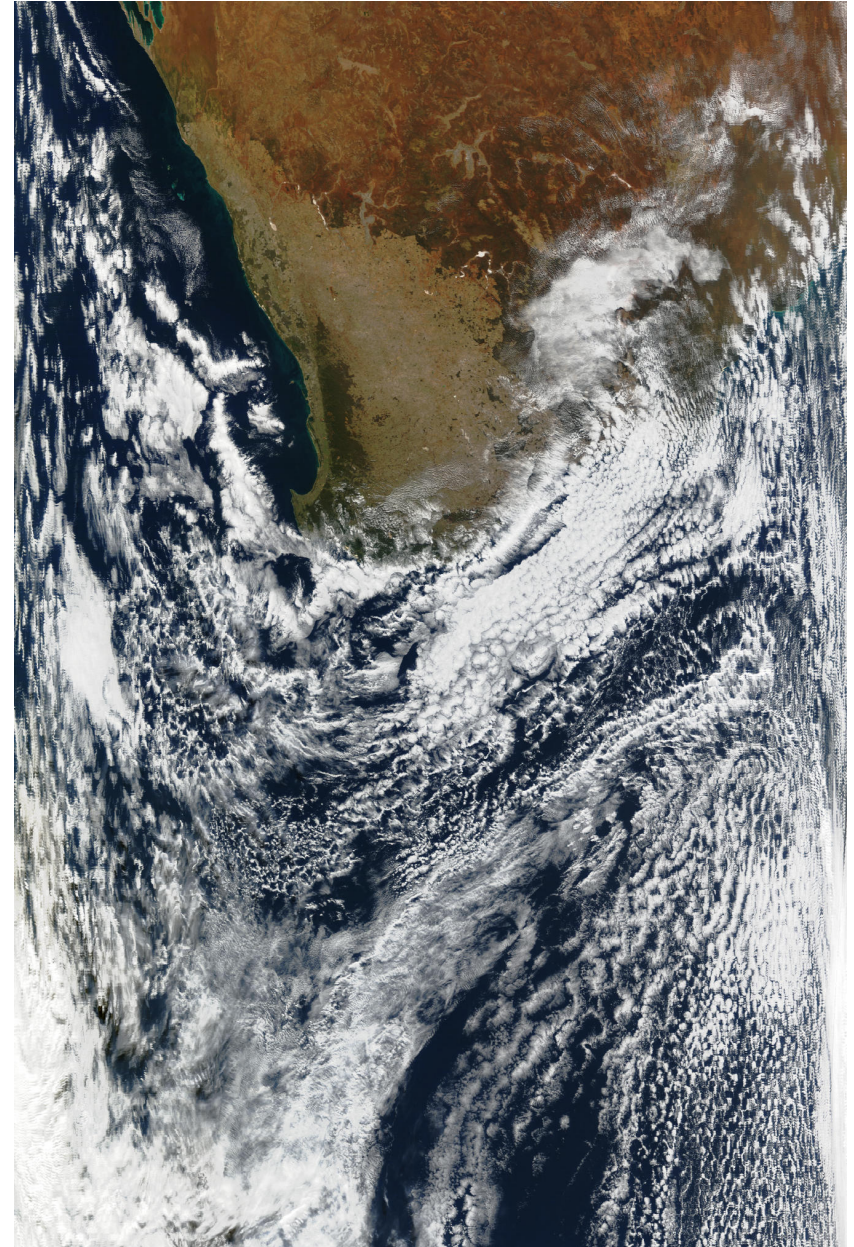
Scan sequence:

1. Solar diffuser
2. Spectroradiometric Calibration Assembly
3. Blackbody
4. Space View
5. Earth scan



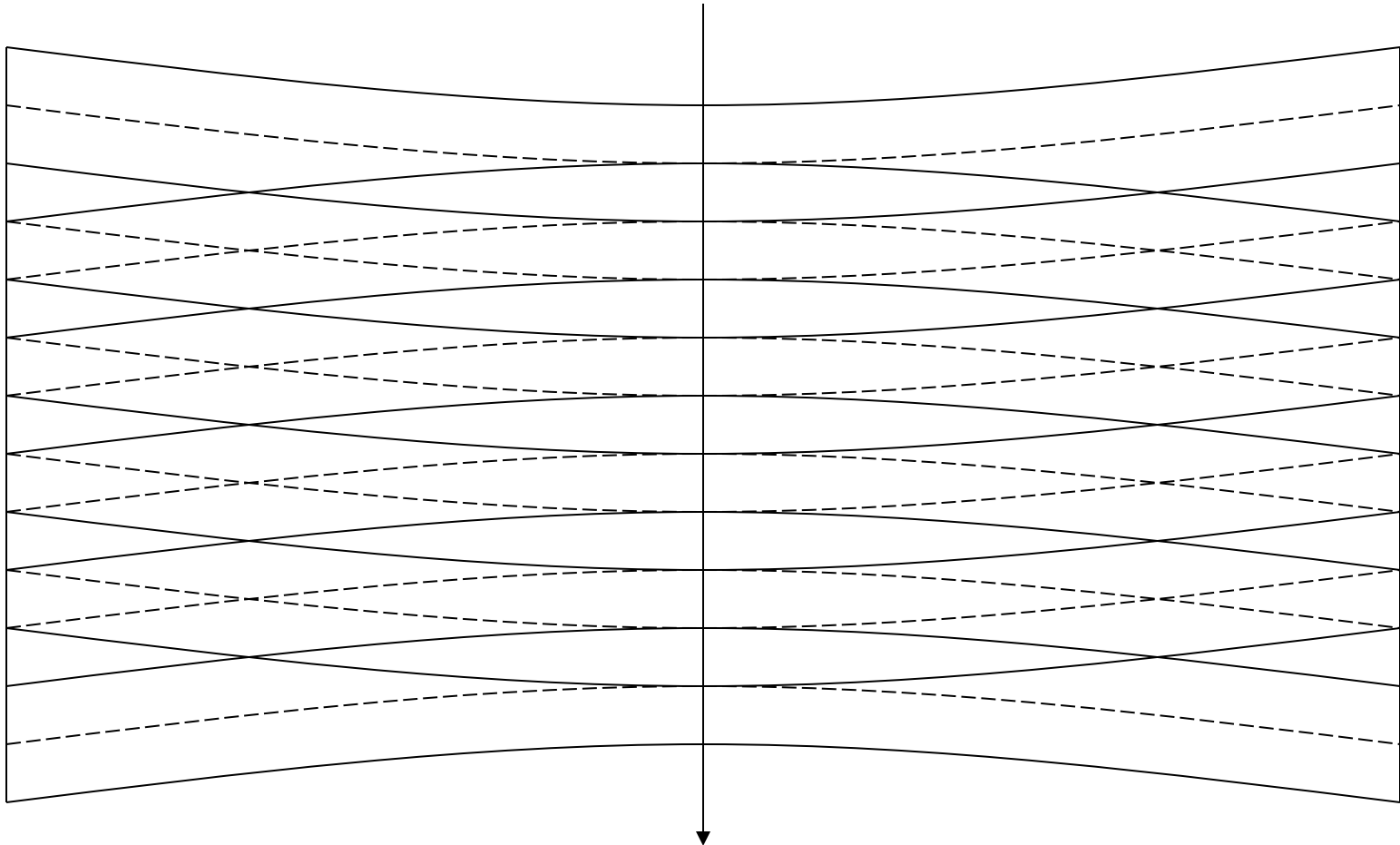
Scan direction →

Flight direction ↓



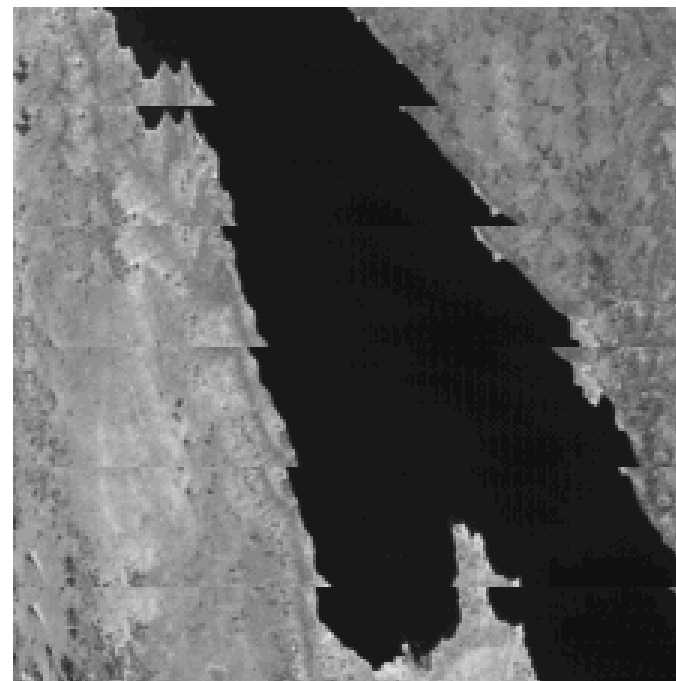
# MODIS Bowtie Artifacts

Consecutive “bowtie” shaped scans are contiguous at nadir, and overlap as scan angle increases...





## MODIS bowtie artifacts at edge of swath



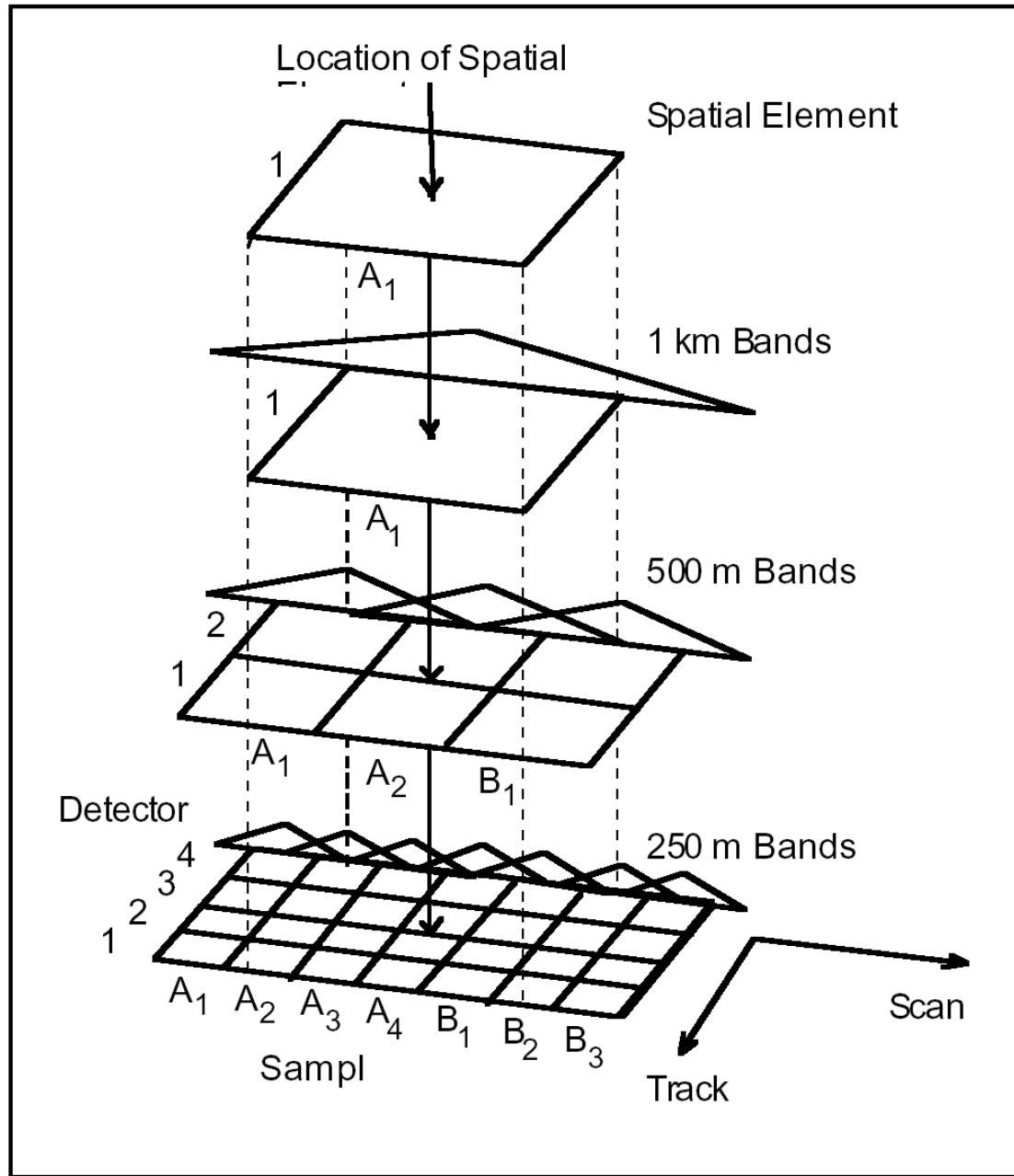
Band 2 (0.87 micron)

250 meter resolution

# Bowtie Artifacts

1. Are not a ‘problem’: they are a consequence of the sensor design
2. Can be removed for visualization purposes by reprojecting the image onto a map
3. Do not affect science algorithms that run on a pixel-by-pixel basis or within one earth scan
4. Will be present on next generation of operational polar orbiting imagers (VIIRS on NPP/NPOESS)

# Inter-band Registration



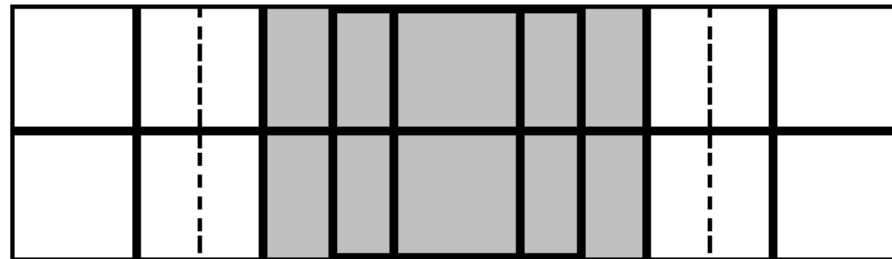


Nominal pixel (solid square)      Actual region sensed (dashed rectangle)

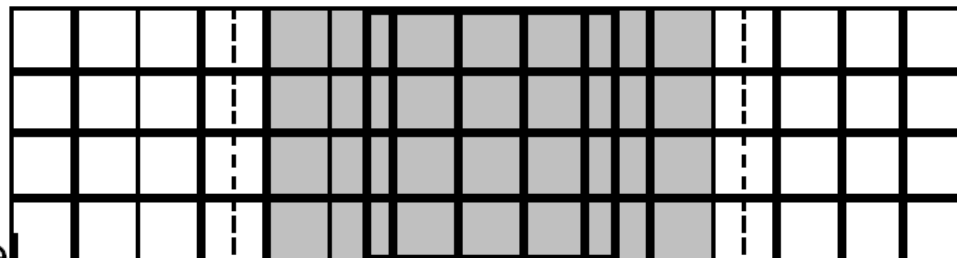
A string of 1000 meter pixels



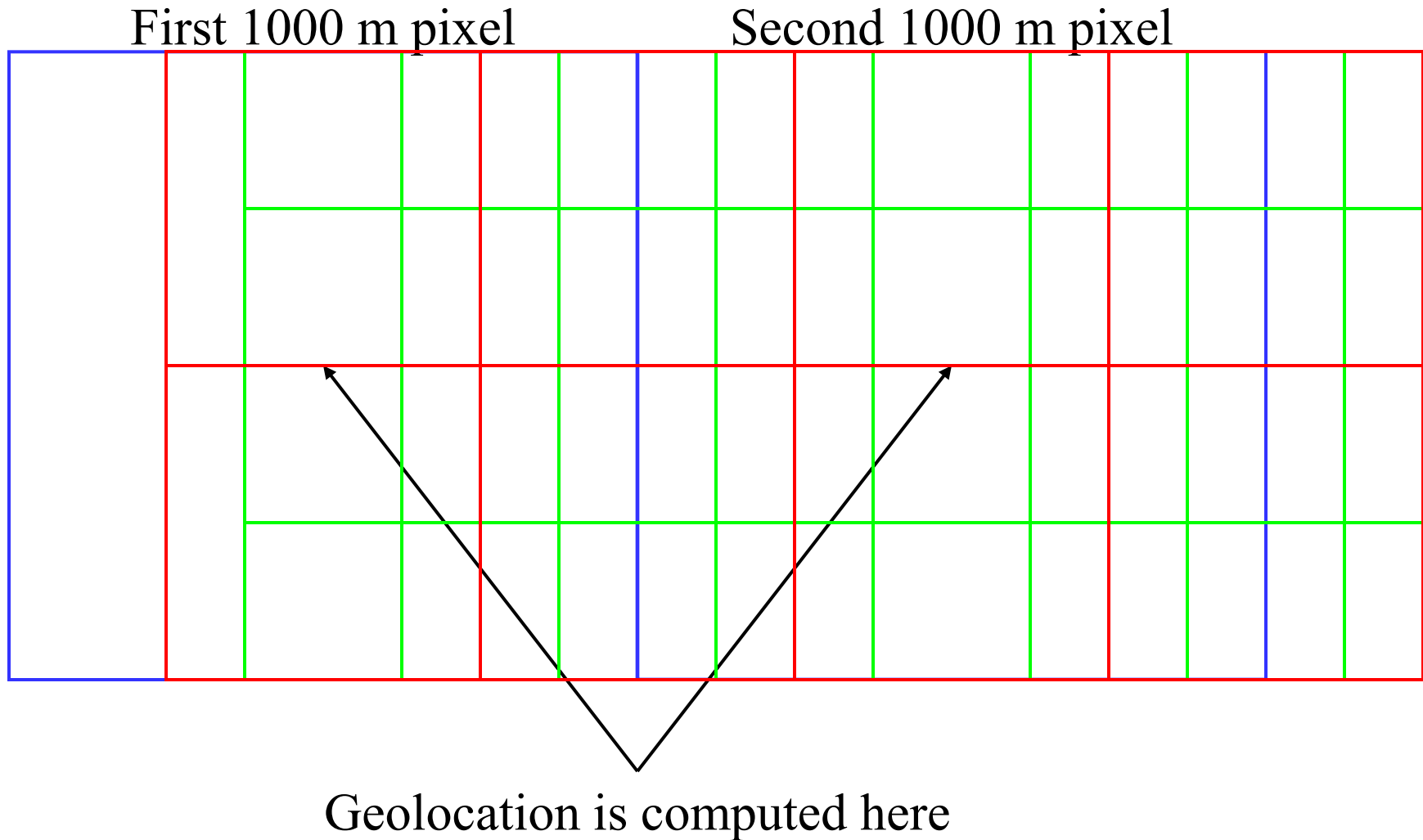
A string of 500 meter pixels overlaying a 1000 m pixel



A string of 250 meter pixels overlaying a 1000 m pixel



# Nominal MODIS inter-band registration



# MODIS Geolocation

Earth locations computed for every 1000 meter pixel (WGS84):

- Geodetic latitude (degrees, -90S to +90N)
- Geodetic longitude (degrees, -180W to +180E)
- Sensor zenith and azimuth (degrees, pixel to sensor)
- Solar zenith and azimuth (degrees, pixel to sun)
- Terrain height above geoid (meters)
- Land/Sea mask
  - 0: Shallow Ocean
  - 1: Land
  - 2: Ocean Coastlines and Lake Shorelines
  - 3: Shallow Inland Water
  - 4: Ephemeral (intermittent) Water
  - 5: Deep Inland Water
  - 6: Moderate or Continental Ocean
  - 7: Deep Ocean

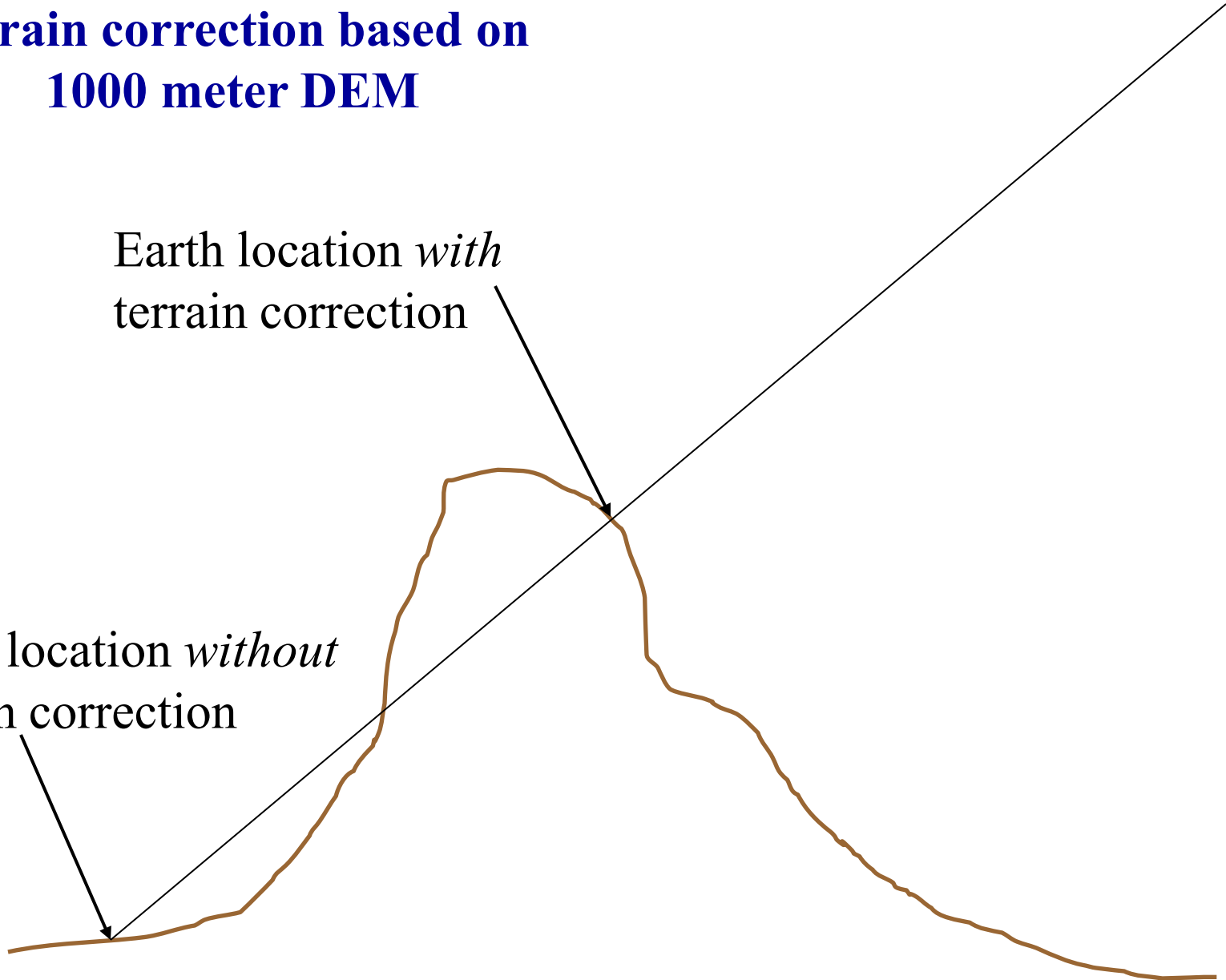


**MODIS geolocation includes terrain correction based on 1000 meter DEM**

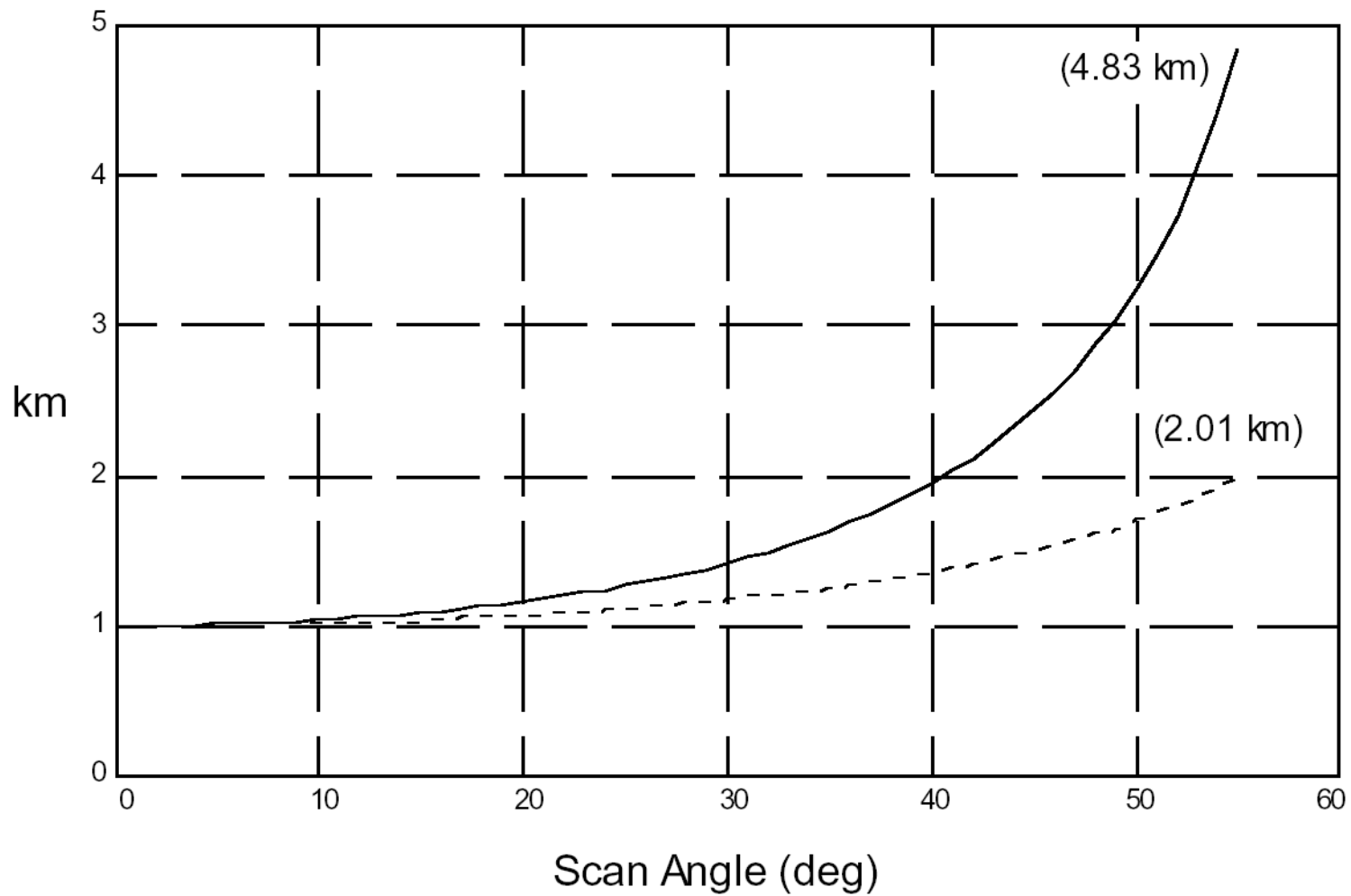
Line of sight to sensor

Earth location *with* terrain correction

Earth location *without* terrain correction



# Growth of MODIS 1 km pixel with scan angle



— Along-scan spatial element size  
-- Along-track spatial element size

# MODIS Geolocation Measured RMS Error (C4)

	Terra	Aqua
Along Scan	38 m	43 m
Along Track	43 m	56 m
# Years	4.0	1.6
Match-ups/day	83	74

Nadir equivalent meters



# Realtime Geolocation

1. For realtime processing, ephemeris and attitude downlinked from spacecraft must be used.
2. Post-processed ephemeris and attitude from NASA GSFC Flight Dynamics may be used for non realtime processing (delay of at least 24 hours after data acquisition)
3. What is the impact on geolocation accuracy of realtime processing?

# MODIS-TERRA geolocation error

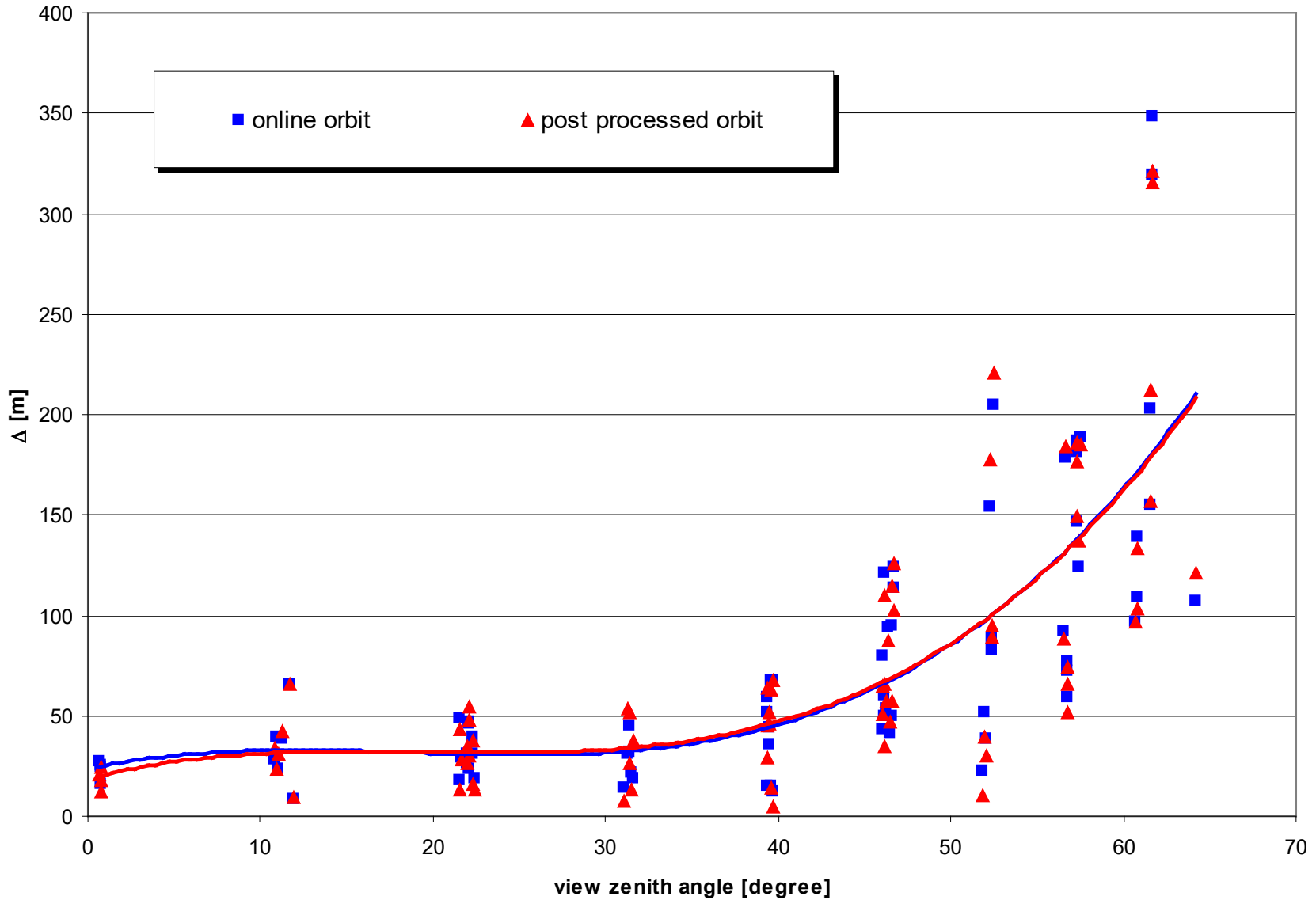


Figure courtesy of Stefan Maier, DOLA

# **Image Artifacts (other than Bowtie)**

## Mirror Side Striping (Band 8, 0.41 $\mu\text{m}$ )



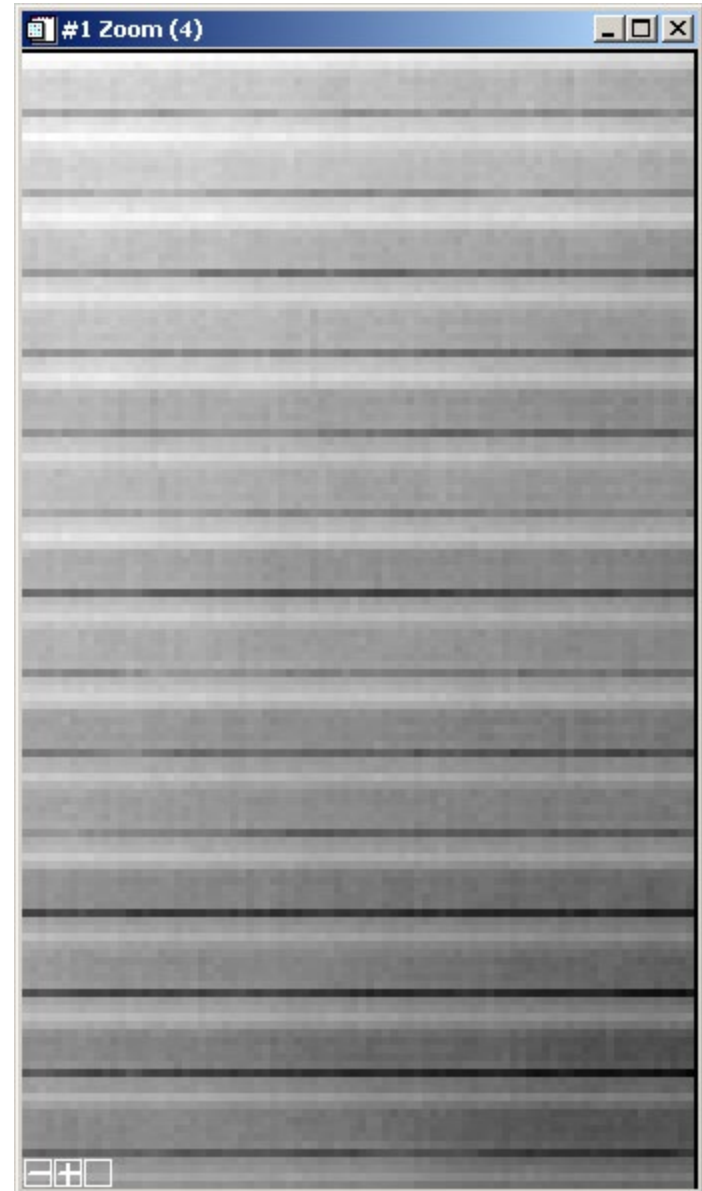
Reflectance, emissivity, or polarization of each scan mirror side not characterized correctly.

*Can be corrected.*

## Detector Difference Striping (Band 27, 6.7 $\mu\text{m}$ )

Responsivity of each detector  
not characterized correctly.

*Can be corrected.*





## Noisy Detectors (Band 34, 13.6 $\mu\text{m}$ )

Detectors are noisy on a per frame basis and unpredictable from scan to scan.

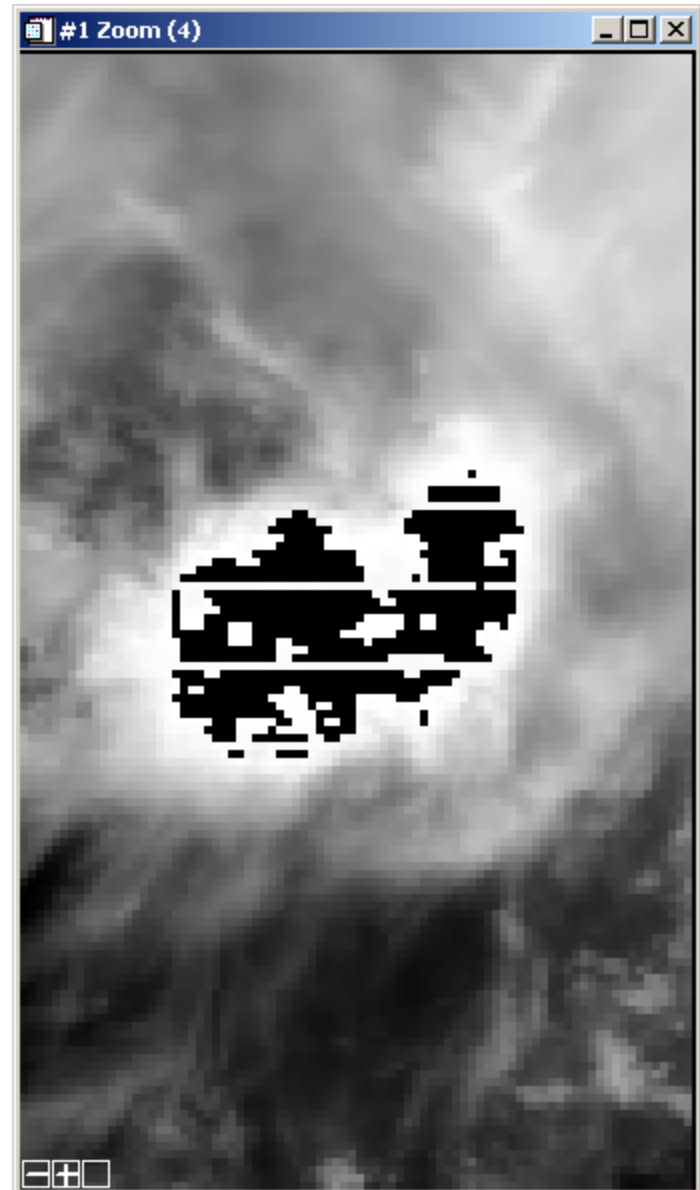
*Difficult to correct.*



## Saturation (Band 2, 0.87 $\mu\text{m}$ )

Signal from earth scene is too large for 12 bit digitization with current gain settings.

*Workaround available.*



# Handling Saturation in Bands 1-5

## Problem:

- Bright cloud tops cause bands 1-5 to saturate, and the MODIS Cloud Mask cannot process these pixels correctly. It also makes true color image creation problematic (bands 1, 4, 3).

## Approach:

- Replace saturated pixels with maximum scaled integer.

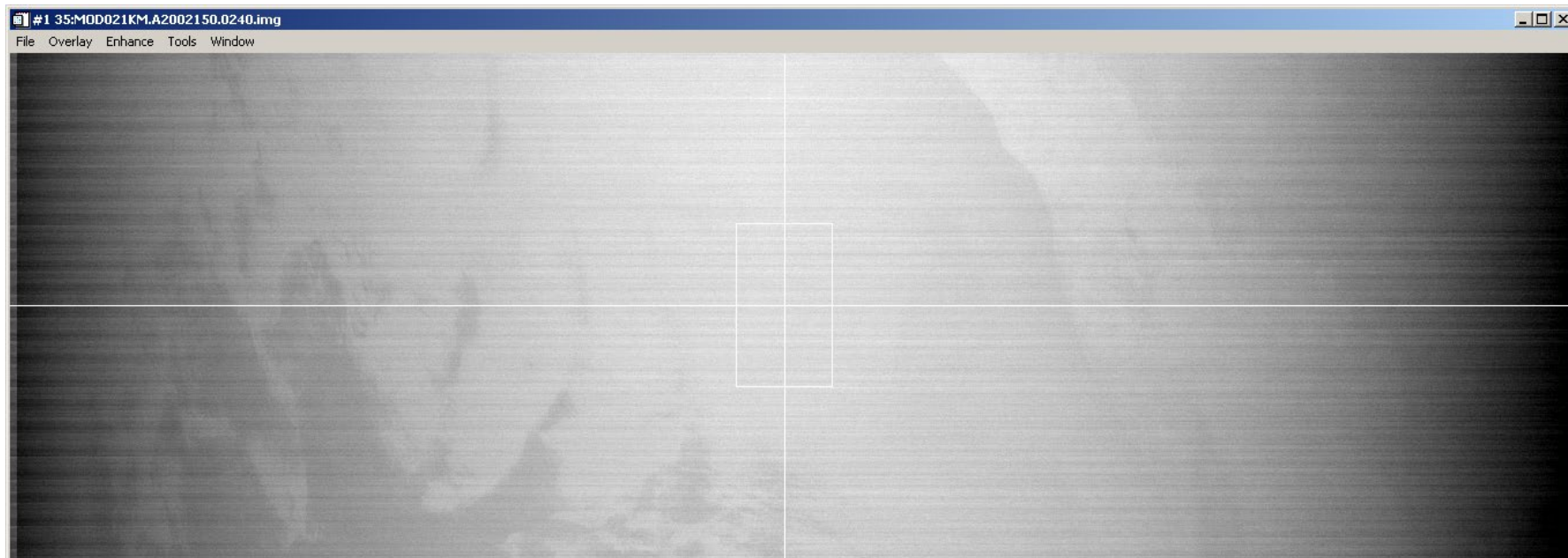
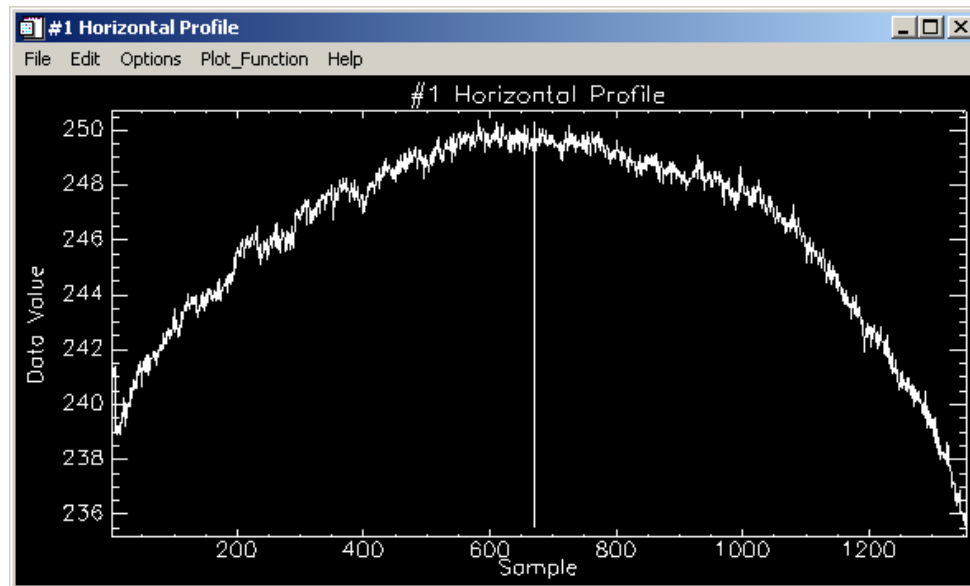
## Method:

1. Check for scaled integer values corresponding to “Detector is saturated” (65533) or “Aggregation algorithm failure” (65528).
2. Replace these values with maximum allowed scaled integer (from `valid_range` attribute).

## Response vs. Scan Angle (Band 35, 13.9 $\mu\text{m}$ )

Scan mirror reflectance, emissivity, or polarization not characterized correctly as a function of scan angle.

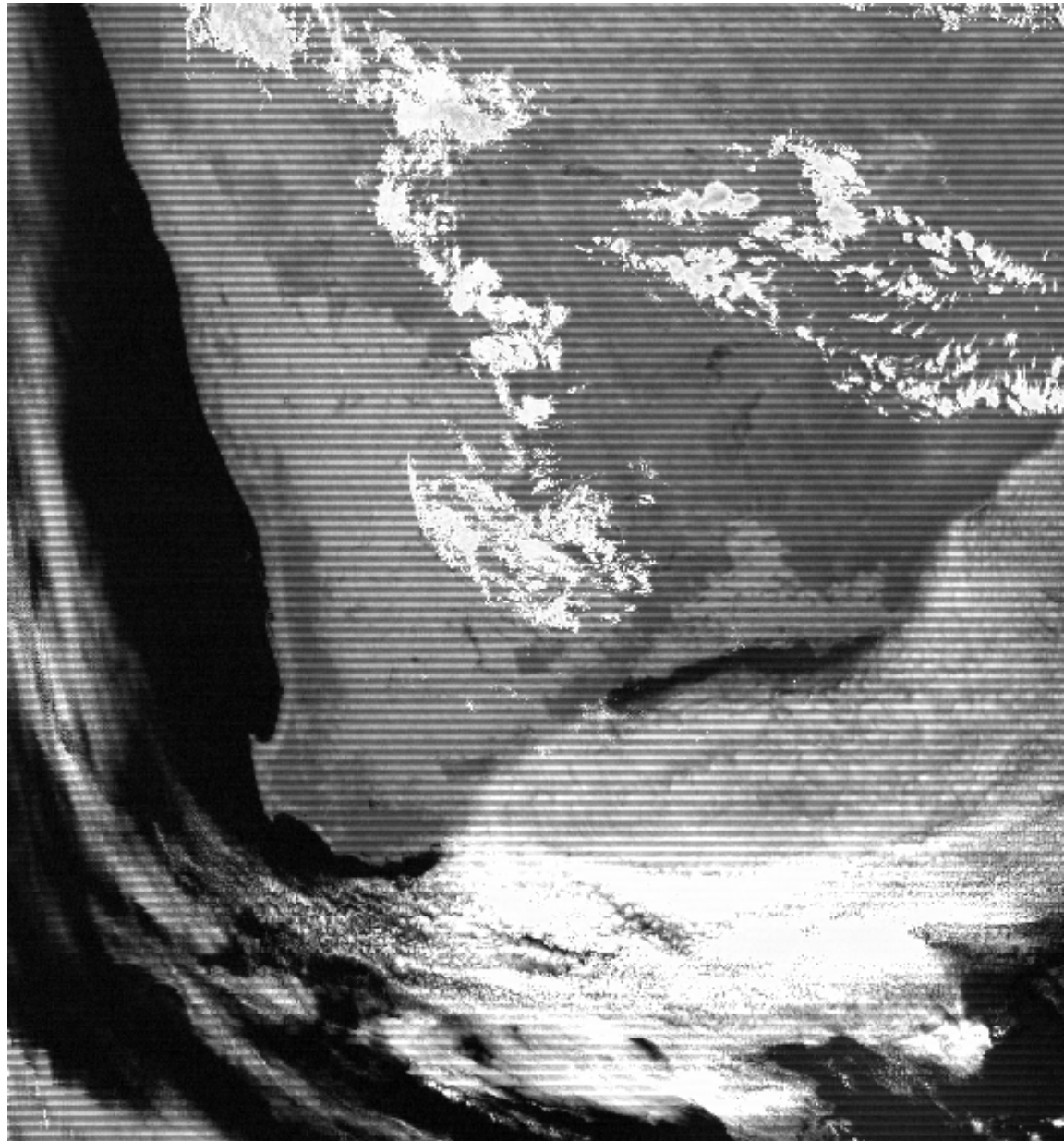
*Deep Space Maneuver on Terra incorporated for collection 5 processing.*



## Band 26 Optical Leak

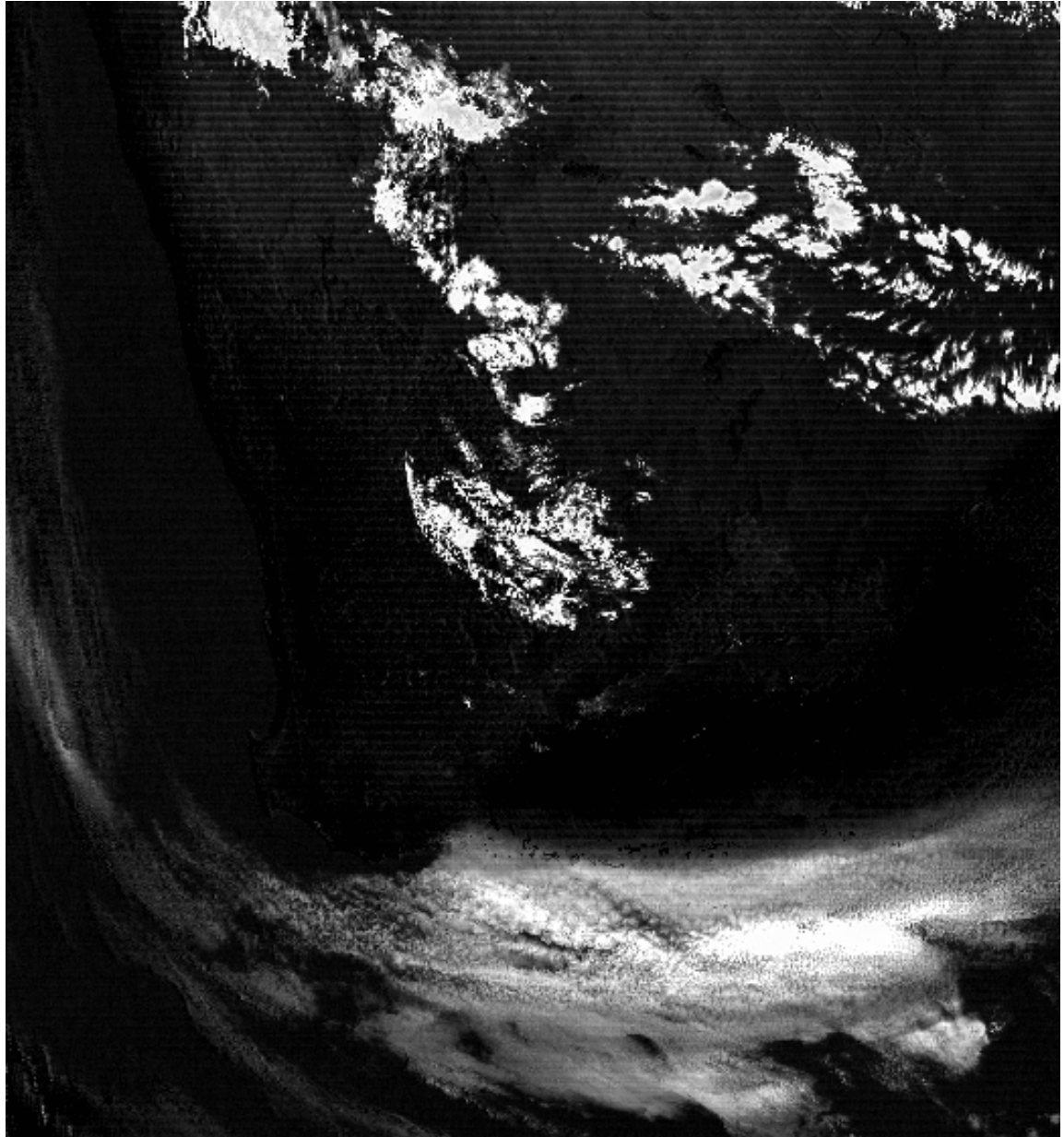
Photons intended for Band 5 detectors (1.24  $\mu\text{m}$ ) leak into Band 26 (1.38  $\mu\text{m}$ ) detectors.

*Correction is operational for collection 4 processing.*



## Band 26 Corrected

Detector dependent correction factors remove the land surface contribution and reduce striping.



# MODIS Performance

<b>Performance Issue</b>	<b>Terra</b>	<b>Aqua</b>
Band 26 Striping and elevated background signal	Correction in L1B now in place for Collect 4.	No Improvement Correction will be necessary
S/MWIR Electronic Crosstalk	An ongoing issue No on-orbit correction	Improved (reduced but not eliminated)
PC LWIR Band Optical Leak	Corrected in L1B; 1-2% uncertainty	Fixed during prelaunch
Detector Striping	Exists in several thermal IR bands. EDF algorithm now available	Improved, but still present. EDF algorithm now available.



# MODIS Performance

## cont.

<b>Performance Issue</b>	<b>Terra</b>	<b>Aqua</b>
5um thermal leak into SWIR	Small influence; Effectively Corrected in L1B	Improved; Correction in L1B TBD
SWIR Band Subsample Departure	On going issue No on-orbit correction	Much Improved
Noisy Detectors	Several in LWIR CO2 bands, one in B24, 25, 27, 28,30	Much Improved (B36 chan 5)
Saturation in Band 2	Saturation on thick water cloud, sunglint regions	Slightly Worse (lower saturation level)

# MODIS Performance cont.

<b>Performance Issue</b>	<b>Terra</b>	<b>Aqua</b>
Scan Mirror reflectance vs. angle of incidence	Much Improved after Deep Space Maneuver	Much Improved Good prelaunch characterization
Dead detectors in SWIR bands	None	B6 severely impacted; B5 has one dead detector

# Destriping

# MODIS Destriping

Striping is a consequence of the calibration algorithm, where each detector is calibrated independently. If the instrument were characterized perfectly, there would be no striping.

However, it is not possible to characterize the instrument perfectly because of time, cost, and schedule constraints.

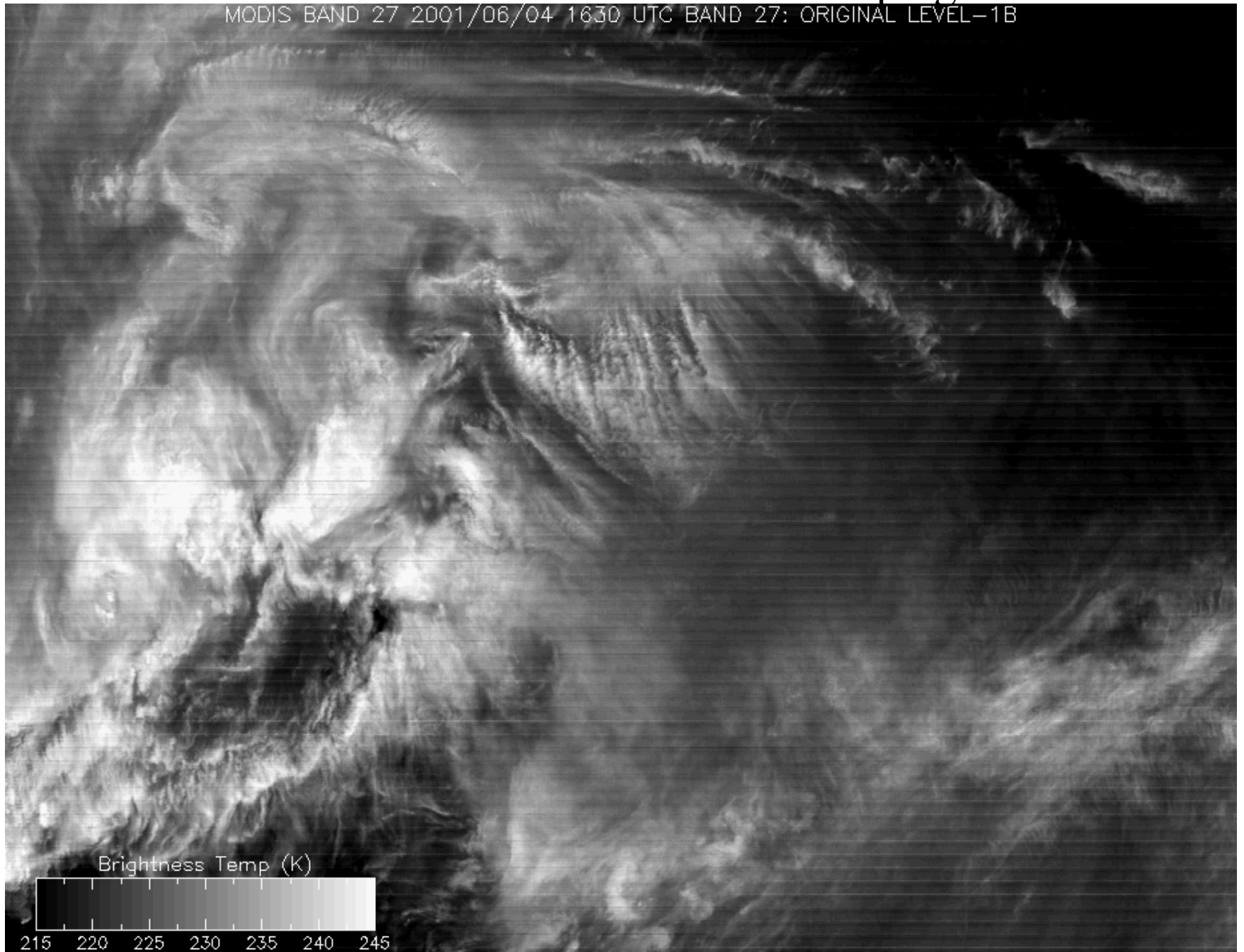
As a result, striping artifacts are introduced by:

- Two-side scan mirror is not characterized perfectly
- Detectors behavior can change in orbit (bias, spectral response)
- Detectors may be noisy

The challenge is to design a destriping algorithm which is effective, fast, and insensitive to instrument changes.

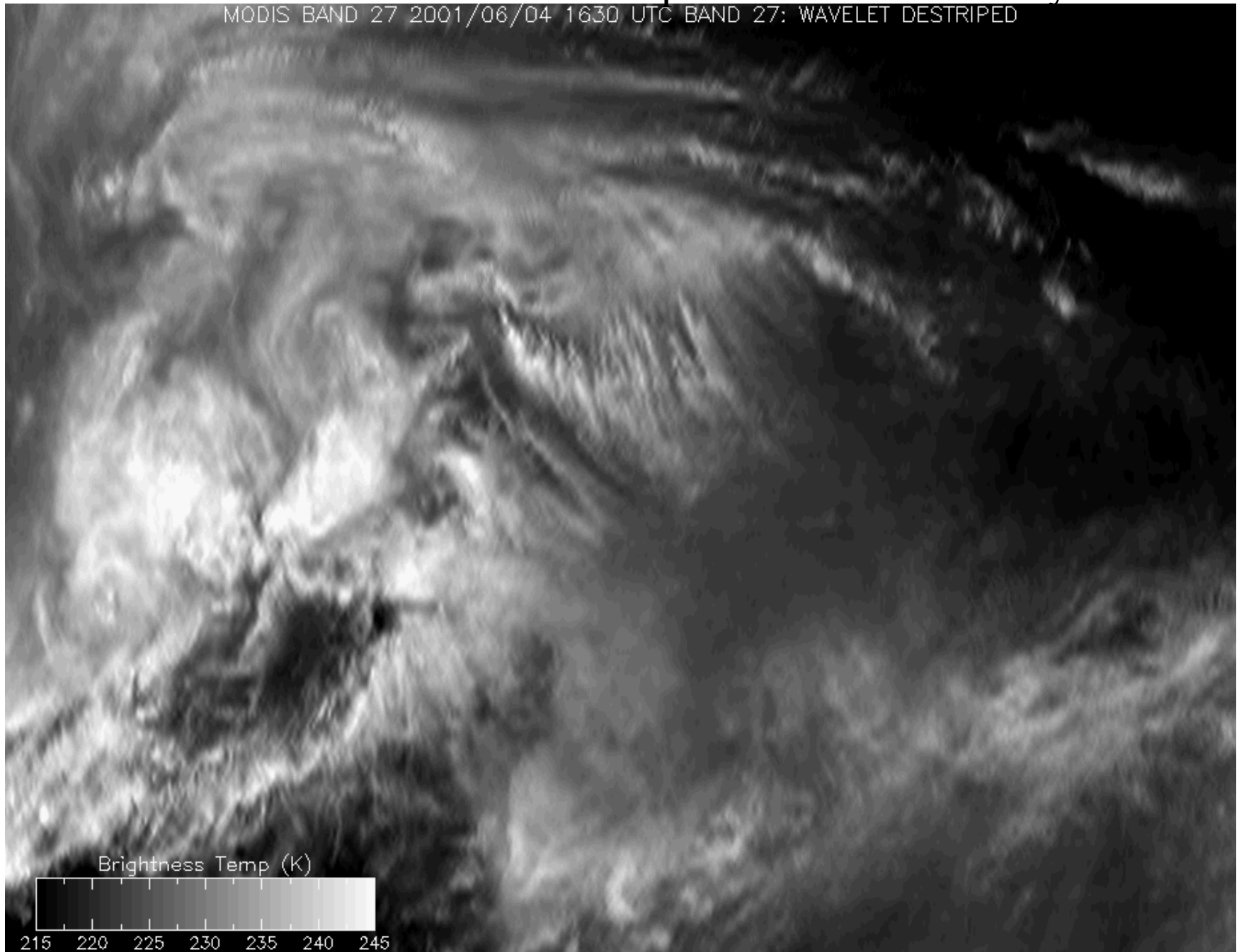
# Terra MODIS Band 27 With Striping

MODIS BAND 27 2001/06/04 1630 UTC BAND 27: ORIGINAL LEVEL-1B



# Terra MODIS Band 27 Destriped via Wavelet Analysis

MODIS BAND 27 2001/06/04 1630 UTC BAND 27: WAVELET DESTRIPE



# Algorithm Details

Weinreb et al., 1989: “Destriping GOES Images by Matching Empirical Distribution Functions”. Remote Sens. Environ., 29, 185-195.

- Accounts for both detector-to-detector and mirror side striping.
- MODIS is treated as a 20 detector instrument in the emissive bands (10 detectors on each mirror side).
- The empirical distribution function (EDF) is computed for each detector (cumulative histogram of relative frequency).
- The EDF for each detector is adjusted to match the EDF of a reference in-family detector.
- Algorithm operates on L1B scaled integers (0-32767).
- Median scaled integer value is restored following destriping.



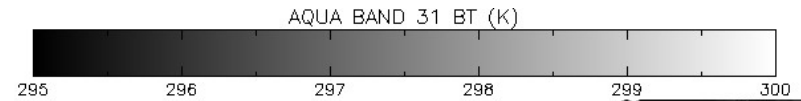
# Destriping Algorithm Implementation

- IDL, FORTRAN-90, and C code for Terra/Aqua L1B 1KM files in DAAC or IMAPP format.
- Requires about 60 seconds to run for each granule.
- Correction LUT is created for each individual granule.
- Uncorrected scaled integers are replaced with corrected scaled integers (could store the correction LUT instead).
- Bands 20, 22-25, 27-30, 33-36 are destriped.
- Impact on bands 31 and 32 is equivocal.
- For Terra MODIS, noisy detectors in some bands are replaced with neighbors (could use interpolation instead):
  - 27 (dets 0, 6); 28 (dets 0, 1); 33 (det 1); 34 (dets 6, 7, 8)
- For Aqua MODIS, no detectors are replaced.

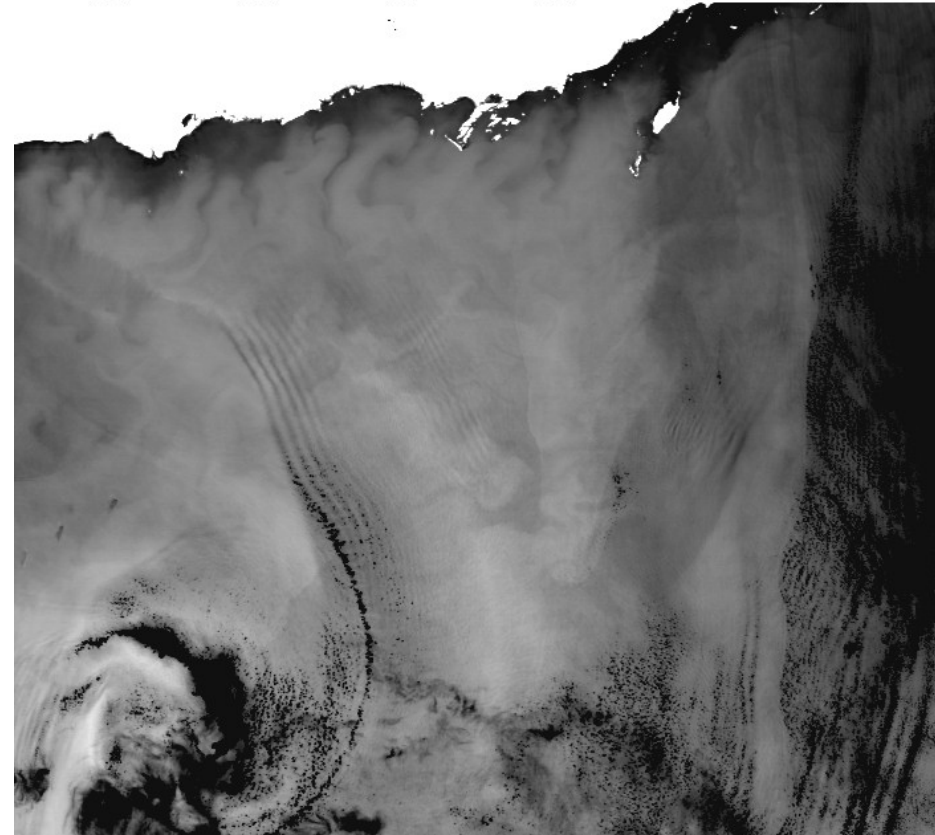
# Aqua Example

MYD021KM.A2003147.0555.003.2003149154542.hdf (May 27)

Northwest Shelf of Western Australia, 700 x 700 pixel subscene



Band 2



Band 31

AQUA BAND 20 BT (K)

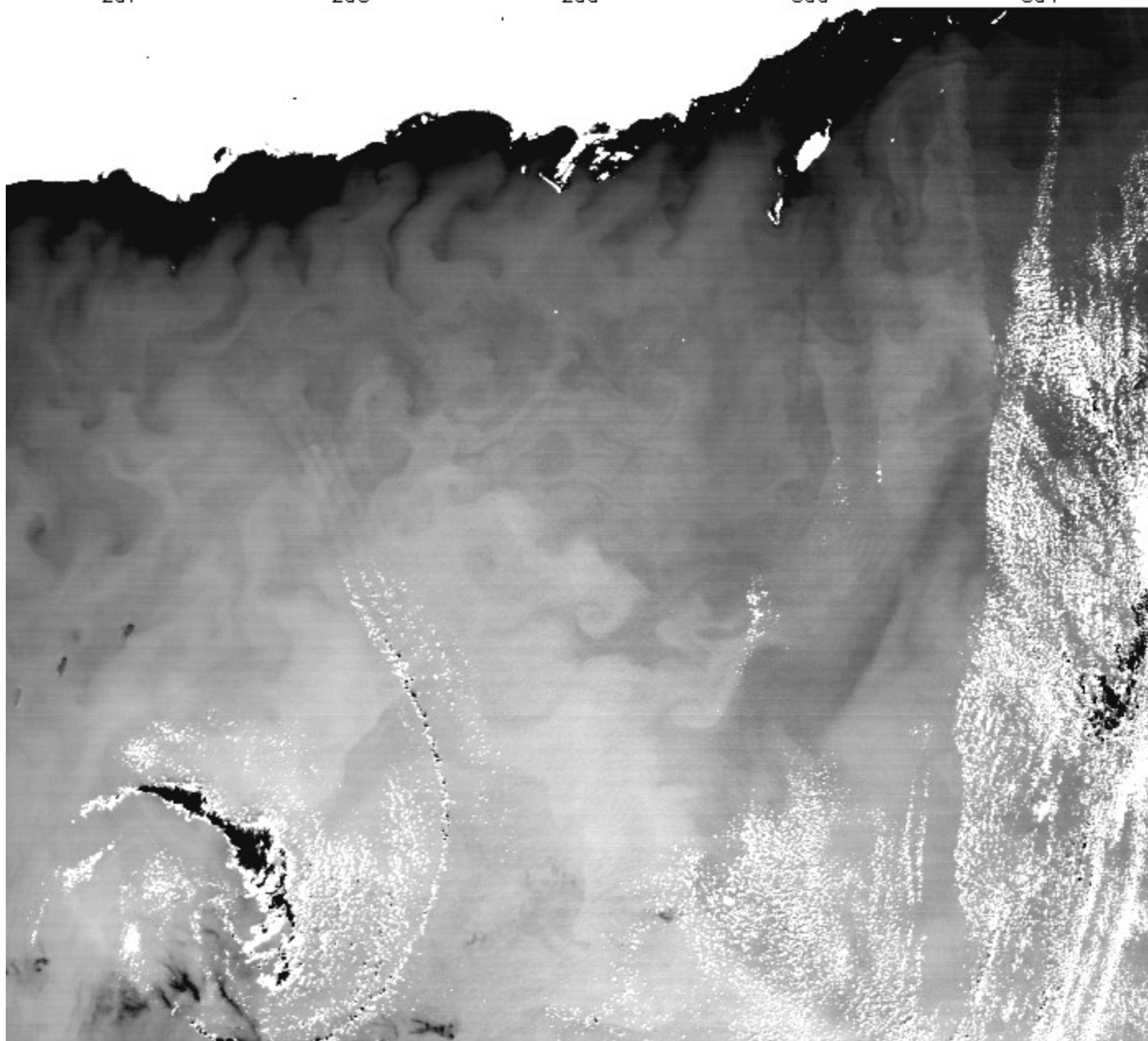
297

298

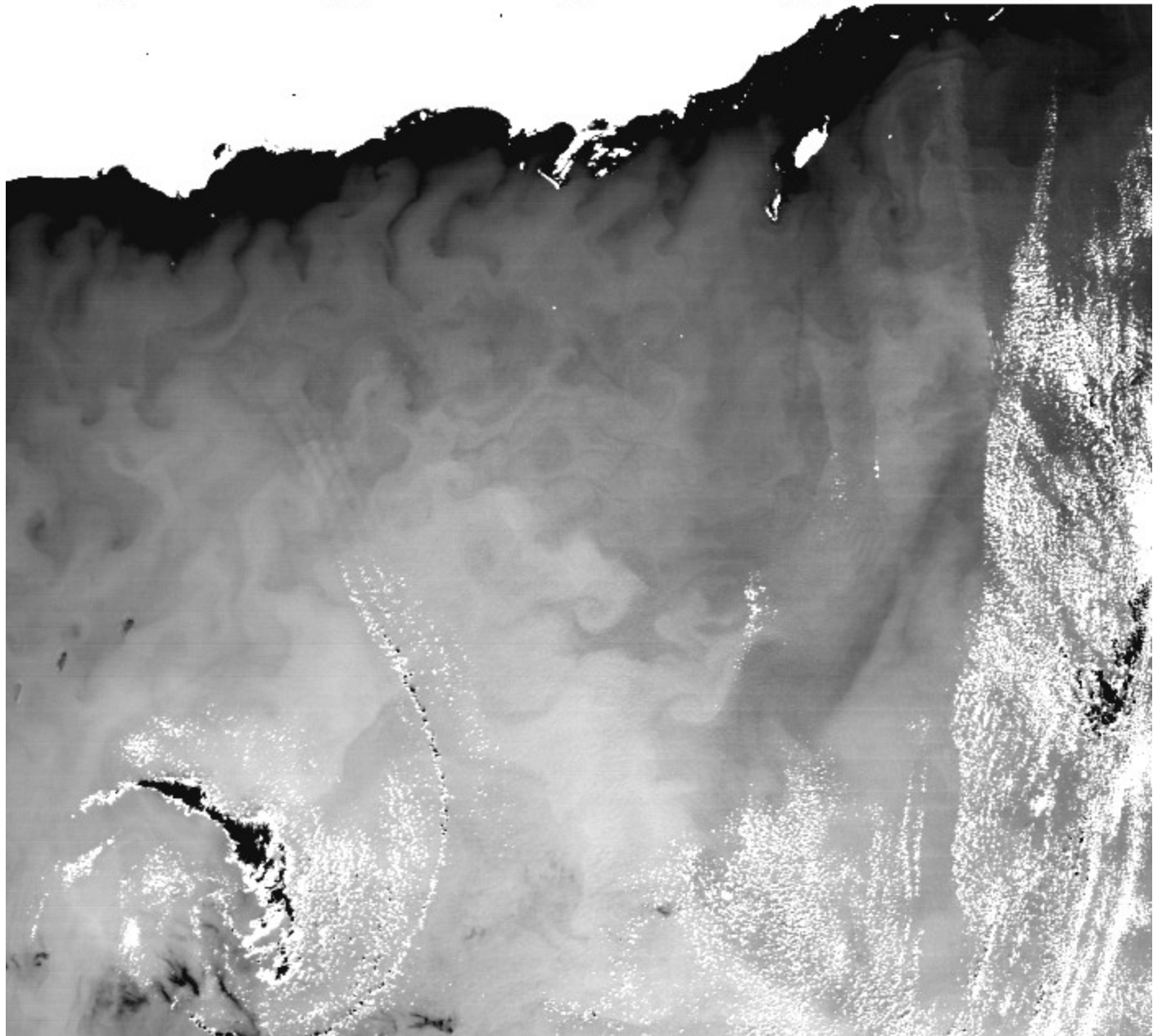
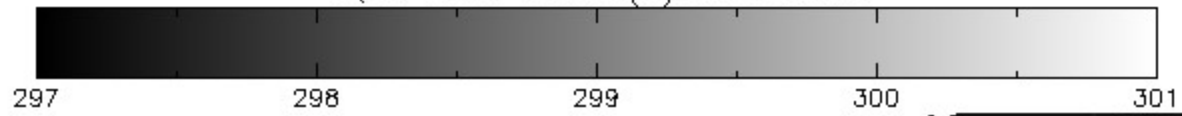
299

300

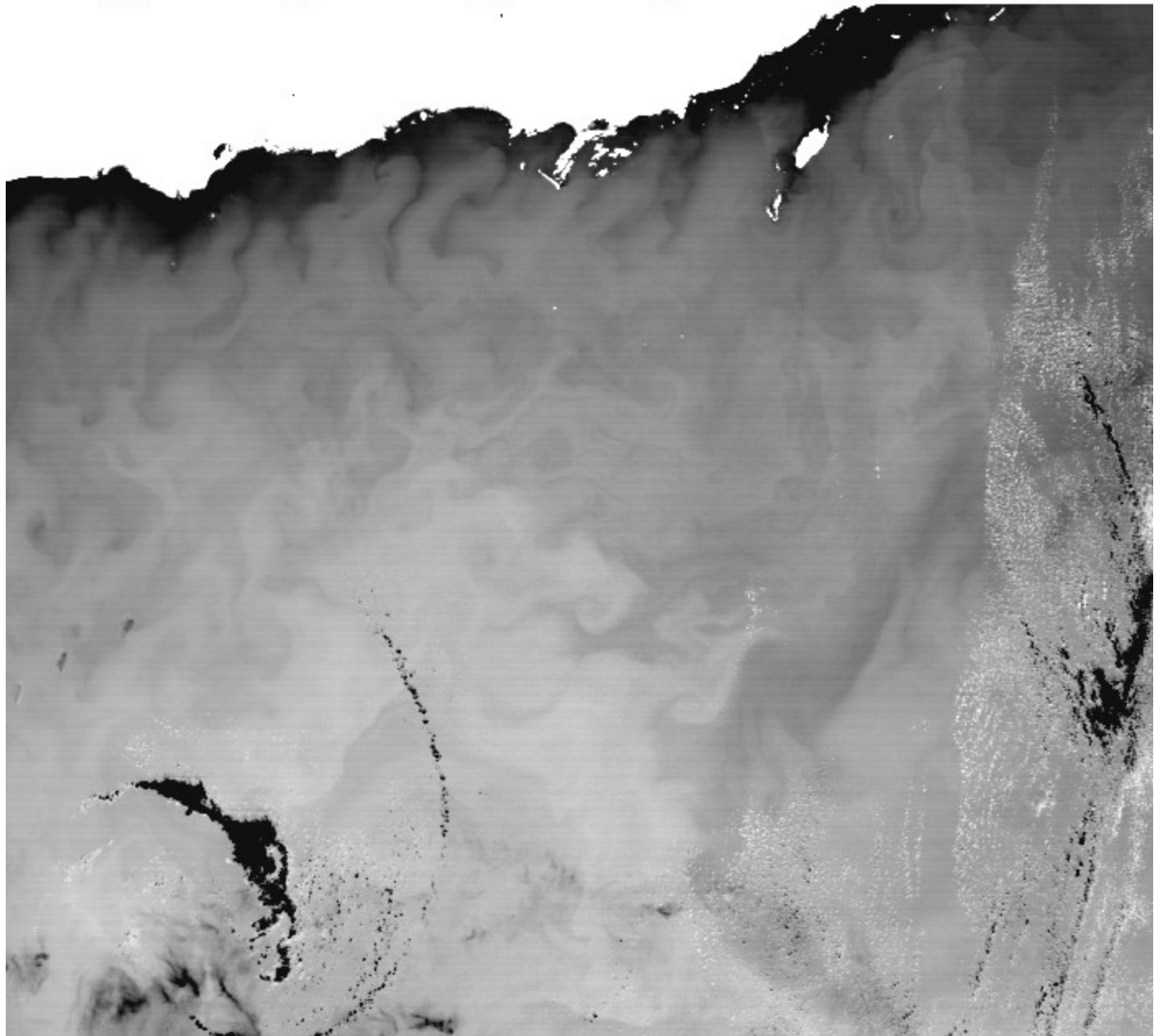
301



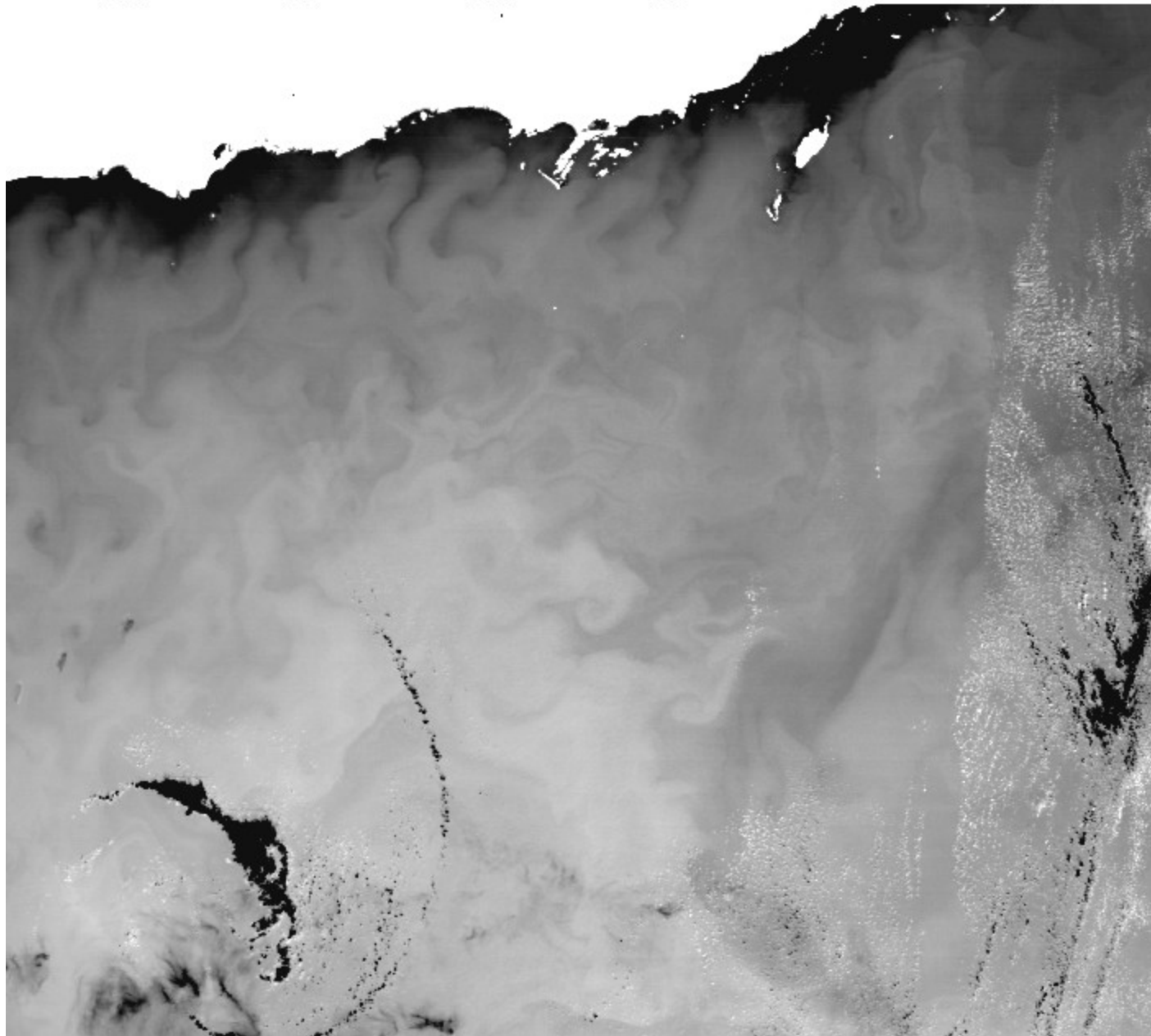
AQUA BAND 20 BT (K): DESTRIPE



AQUA BAND 22 BT (K)

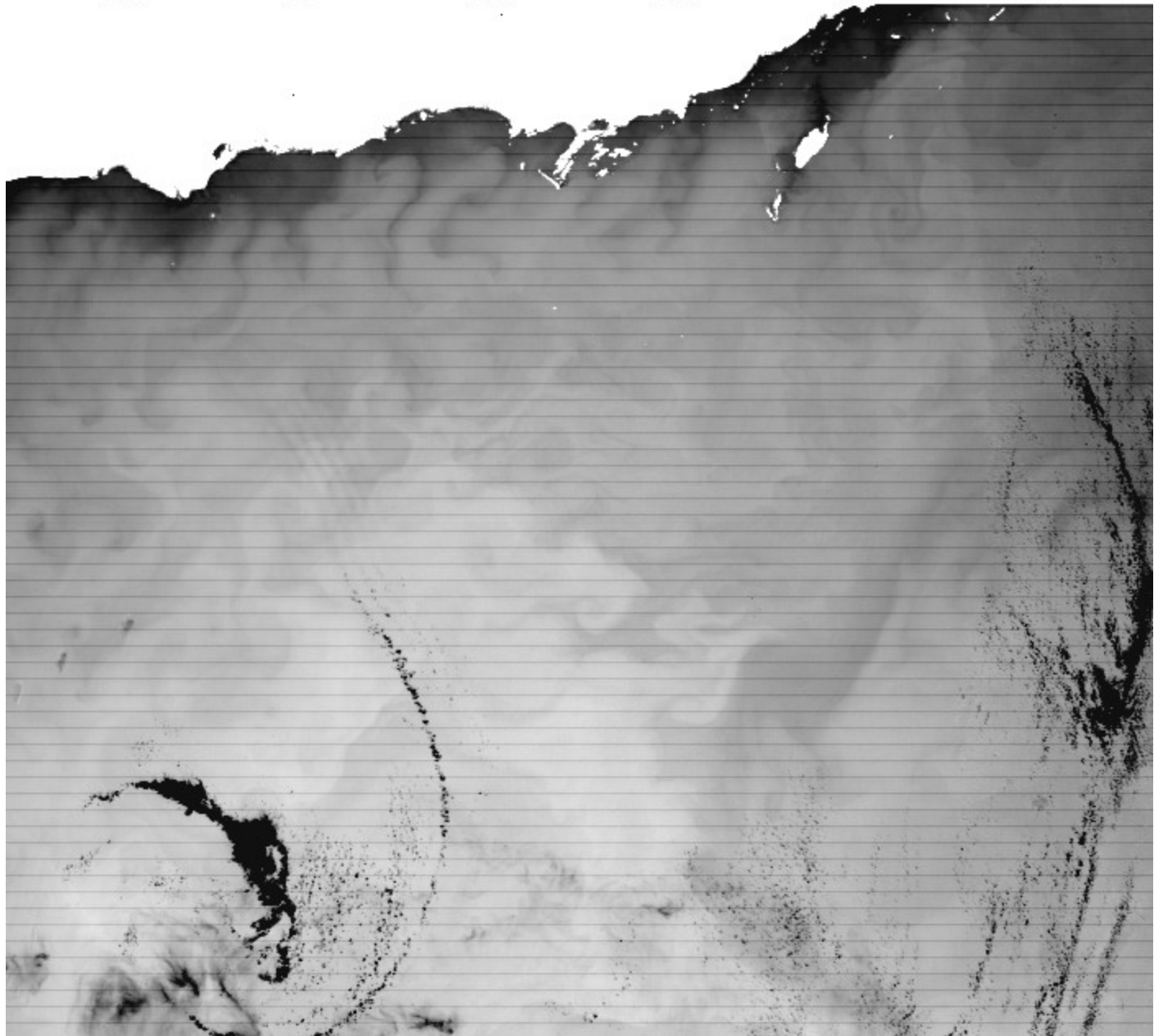


AQUA BAND 22 BT (K): DESTRIPE

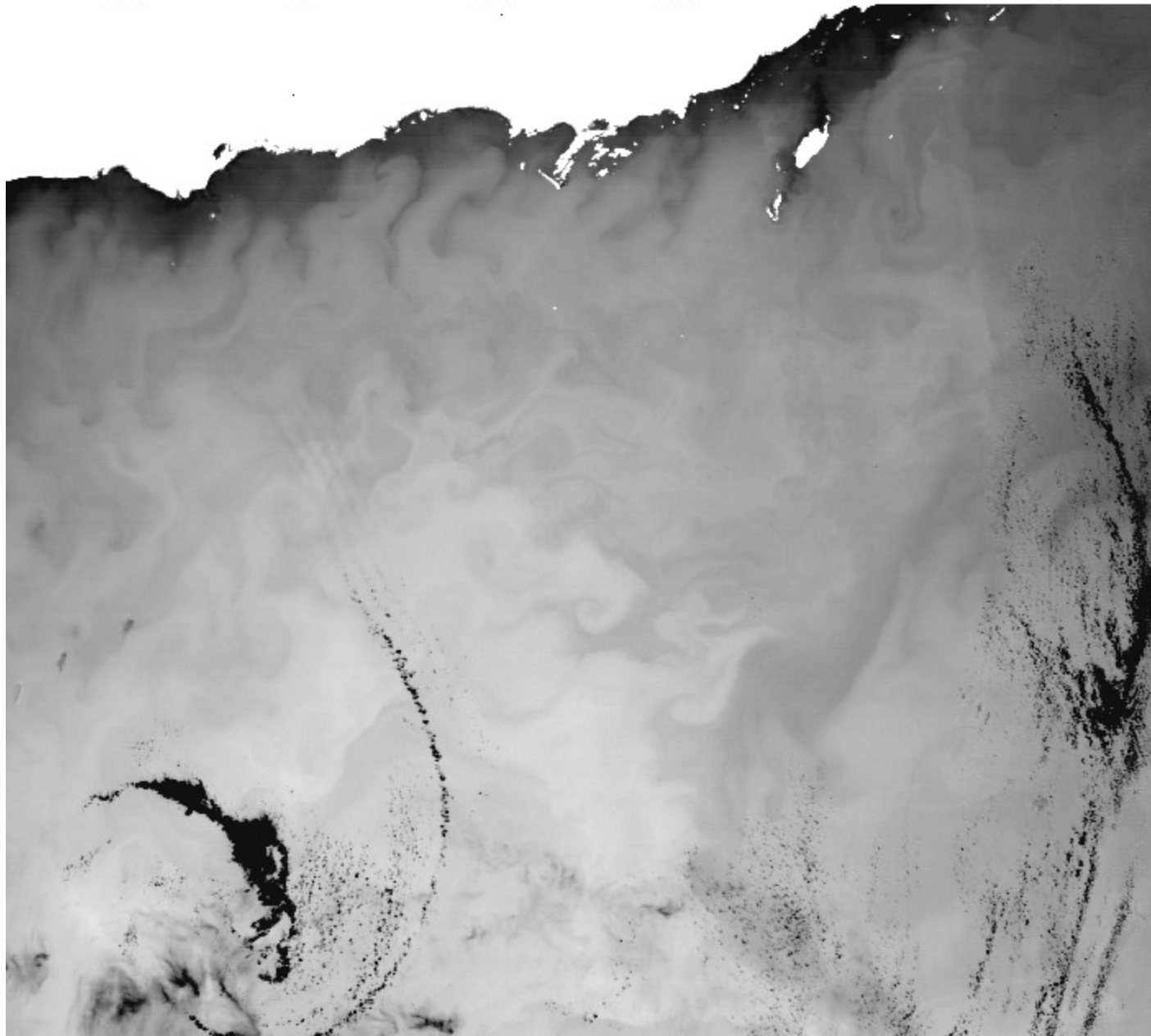




AQUA BAND 23 BT (K)



AQUA BAND 23 BT (K): DESTRIPE



AQUA BAND 24 BT (K)

246

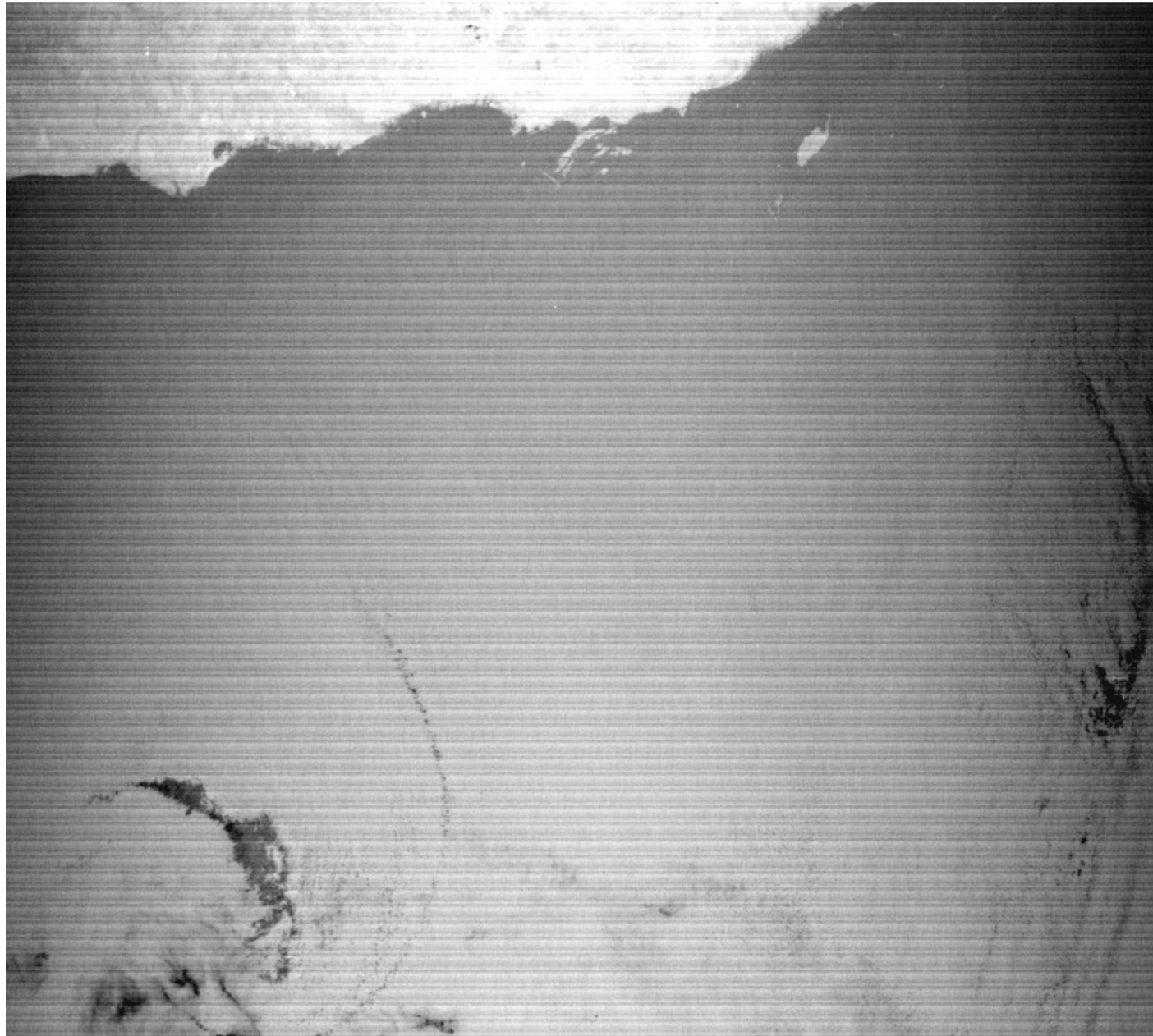
247

248

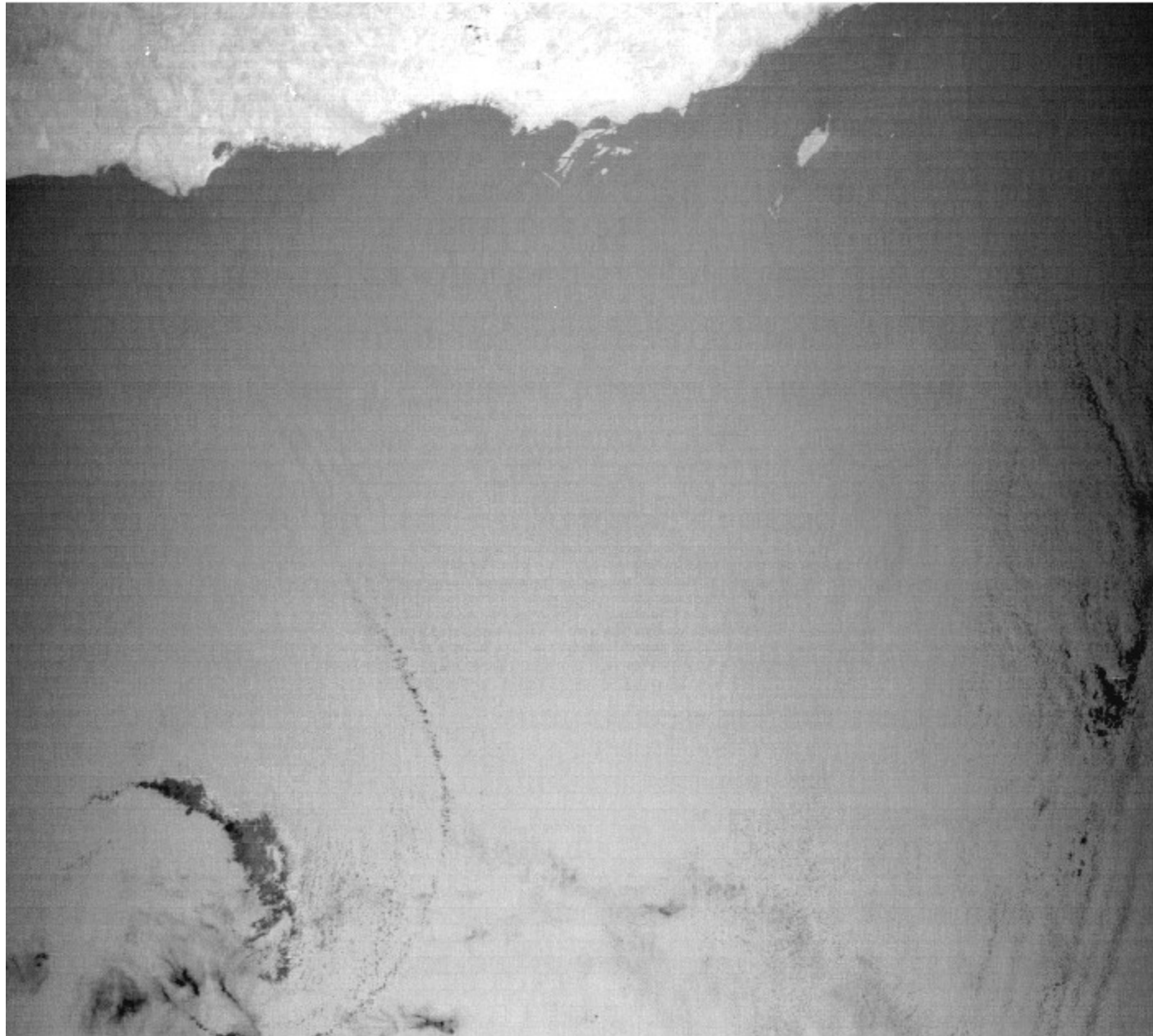
249

250

251



AQUA BAND 24 BT (K): DESTRIPE



AQUA BAND 25 BT (K)

269

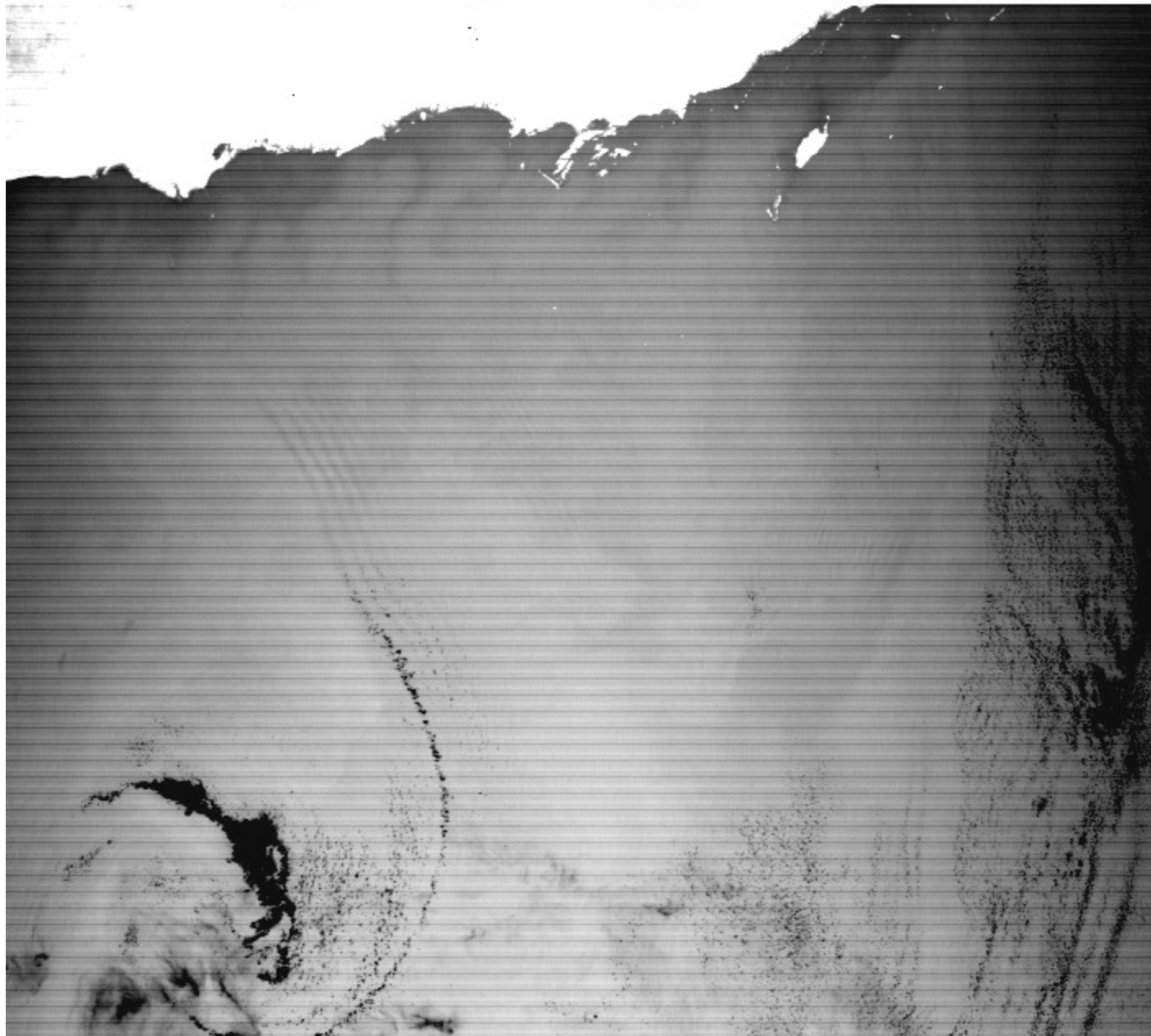
270

271

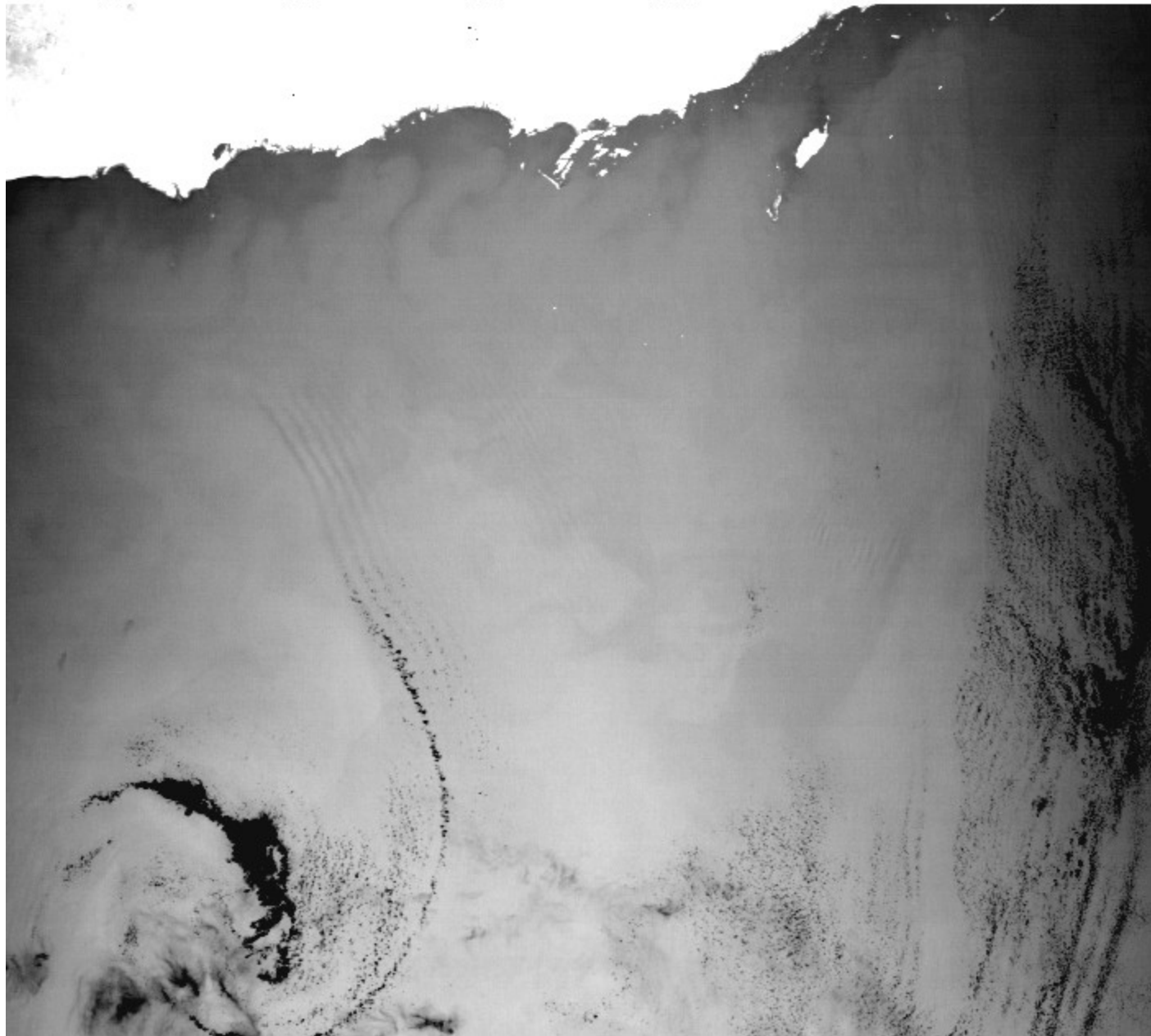
272

273

274

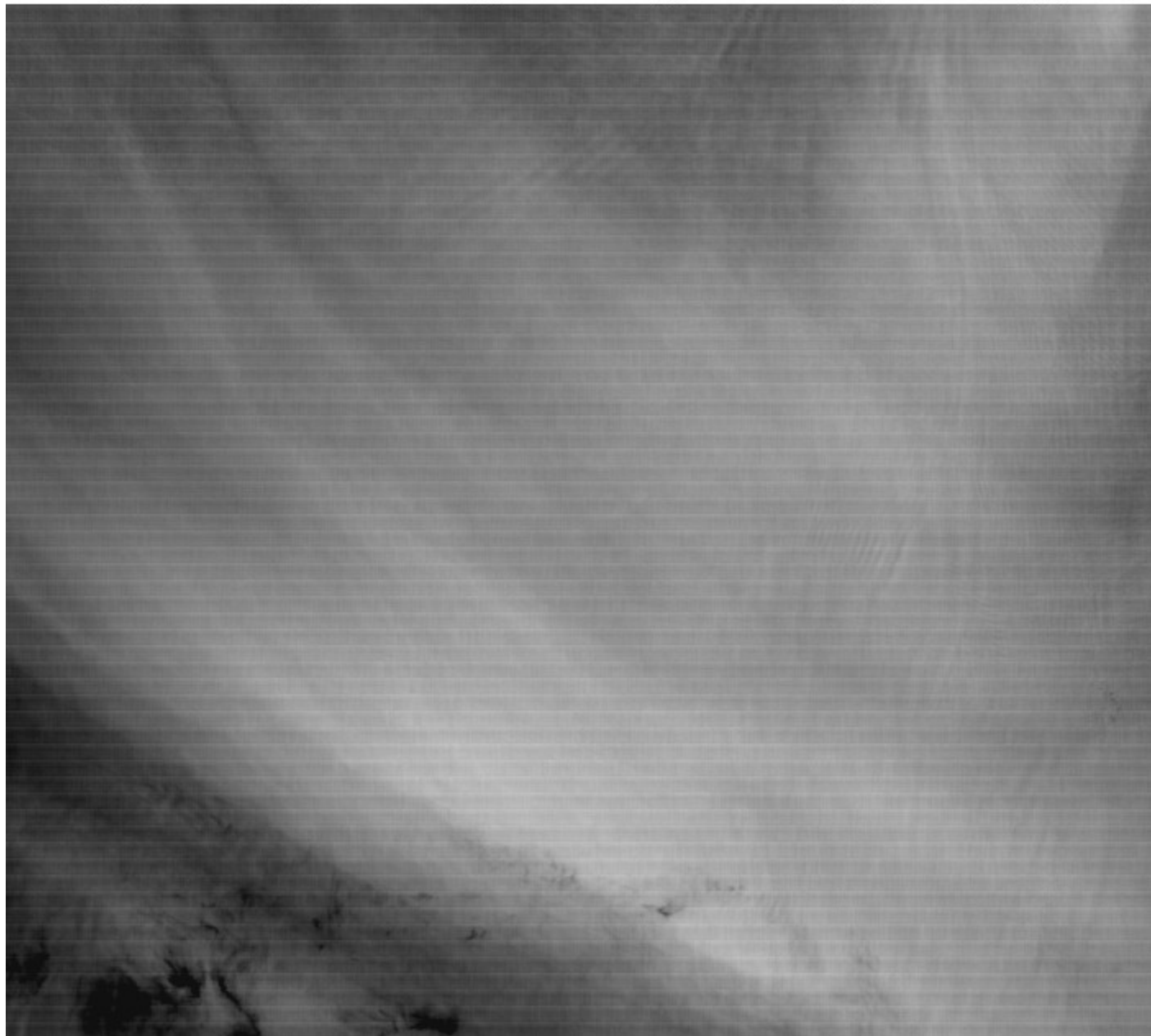


AQUA BAND 25 BT (K): DESTRIPE



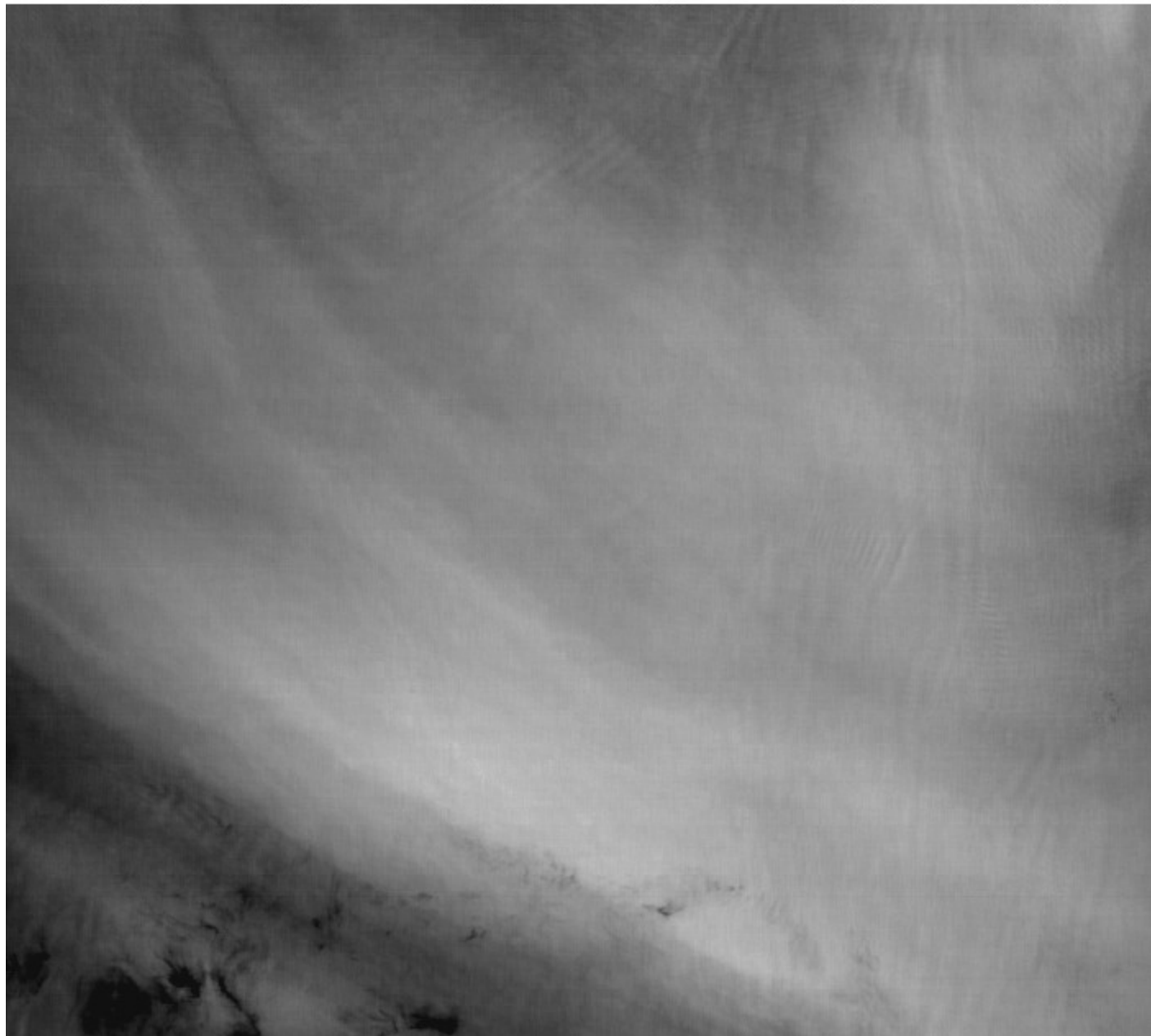


AQUA BAND 27 BT (K)

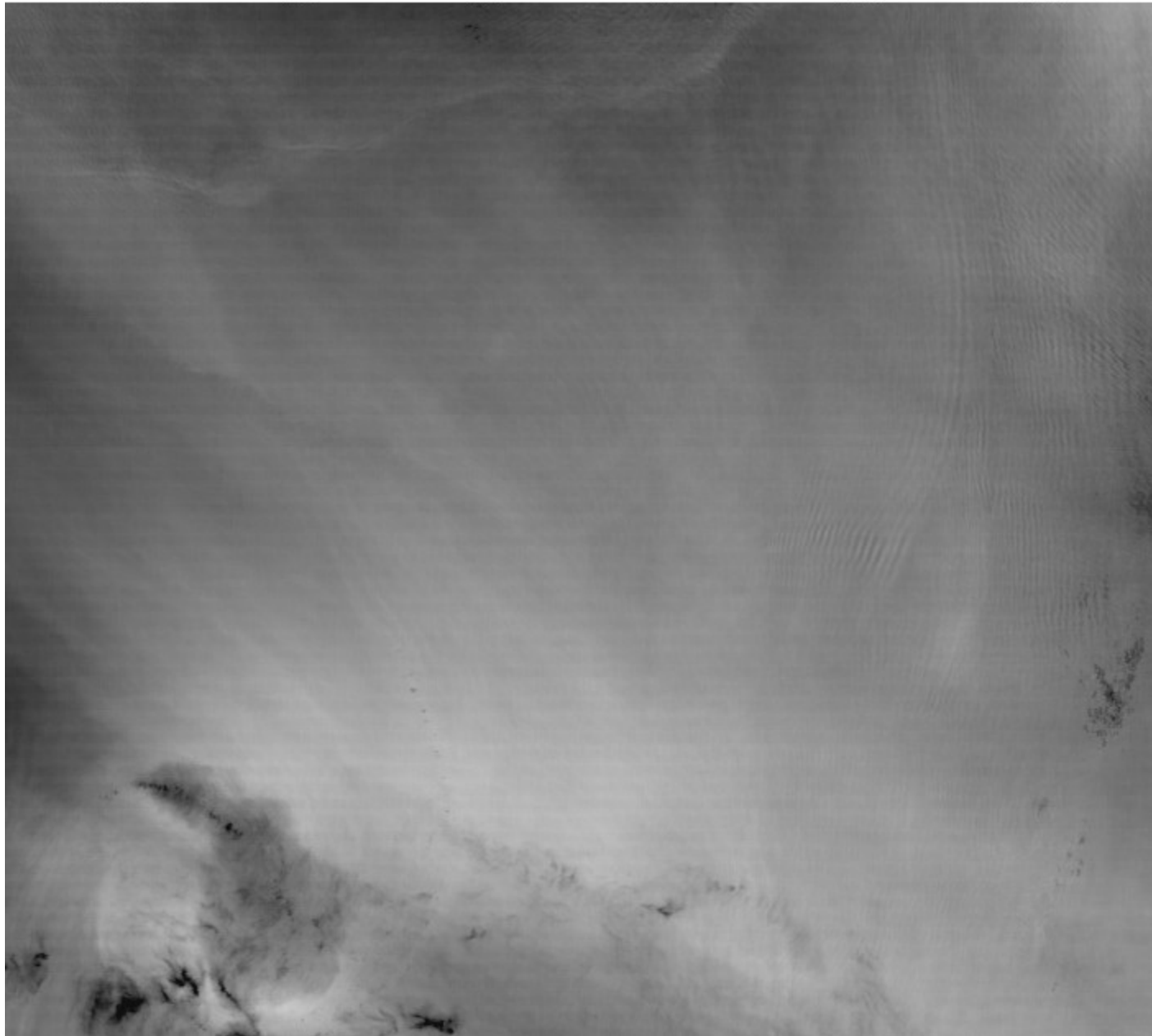




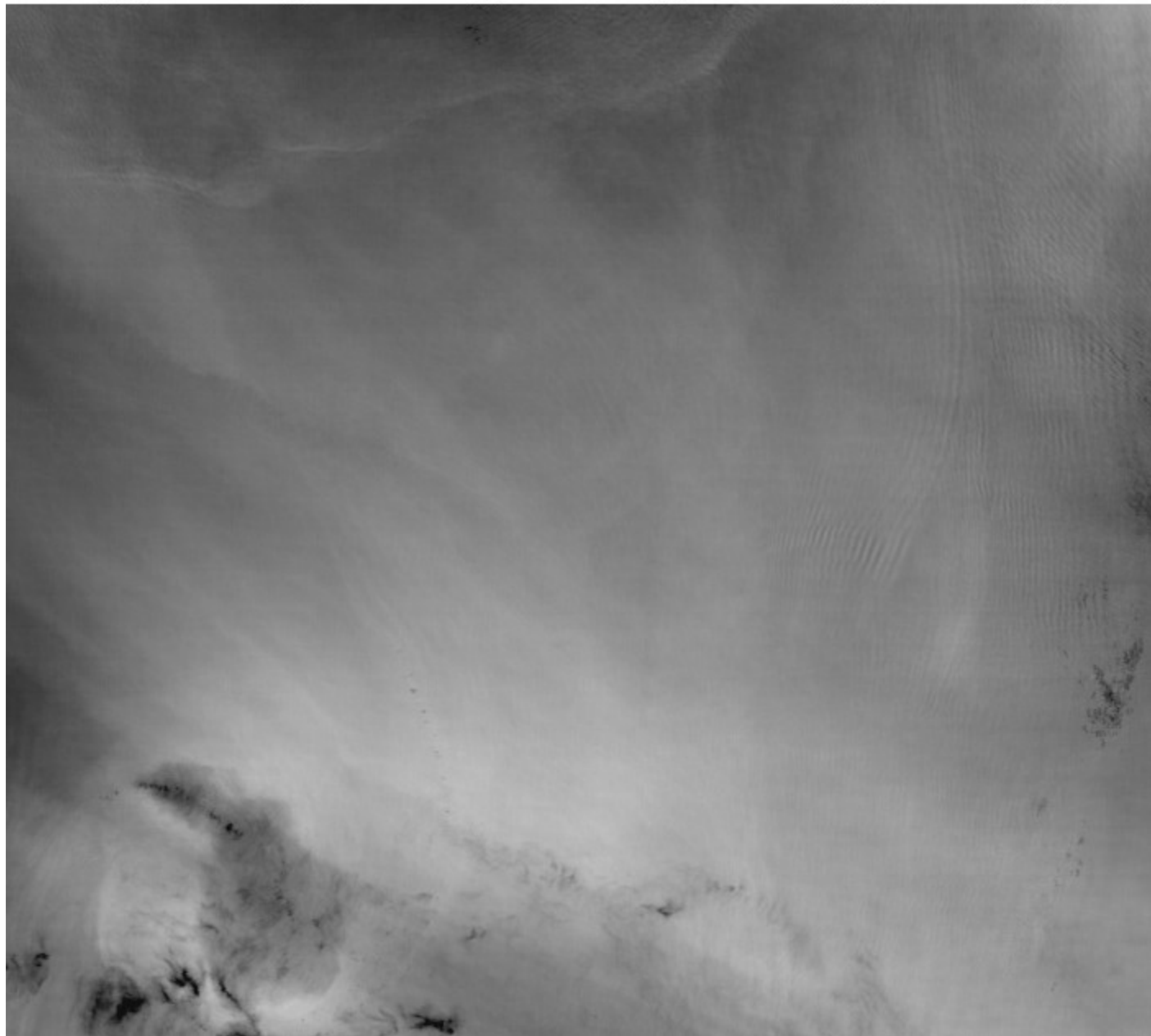
AQUA BAND 27 BT (K): DESTRIPE



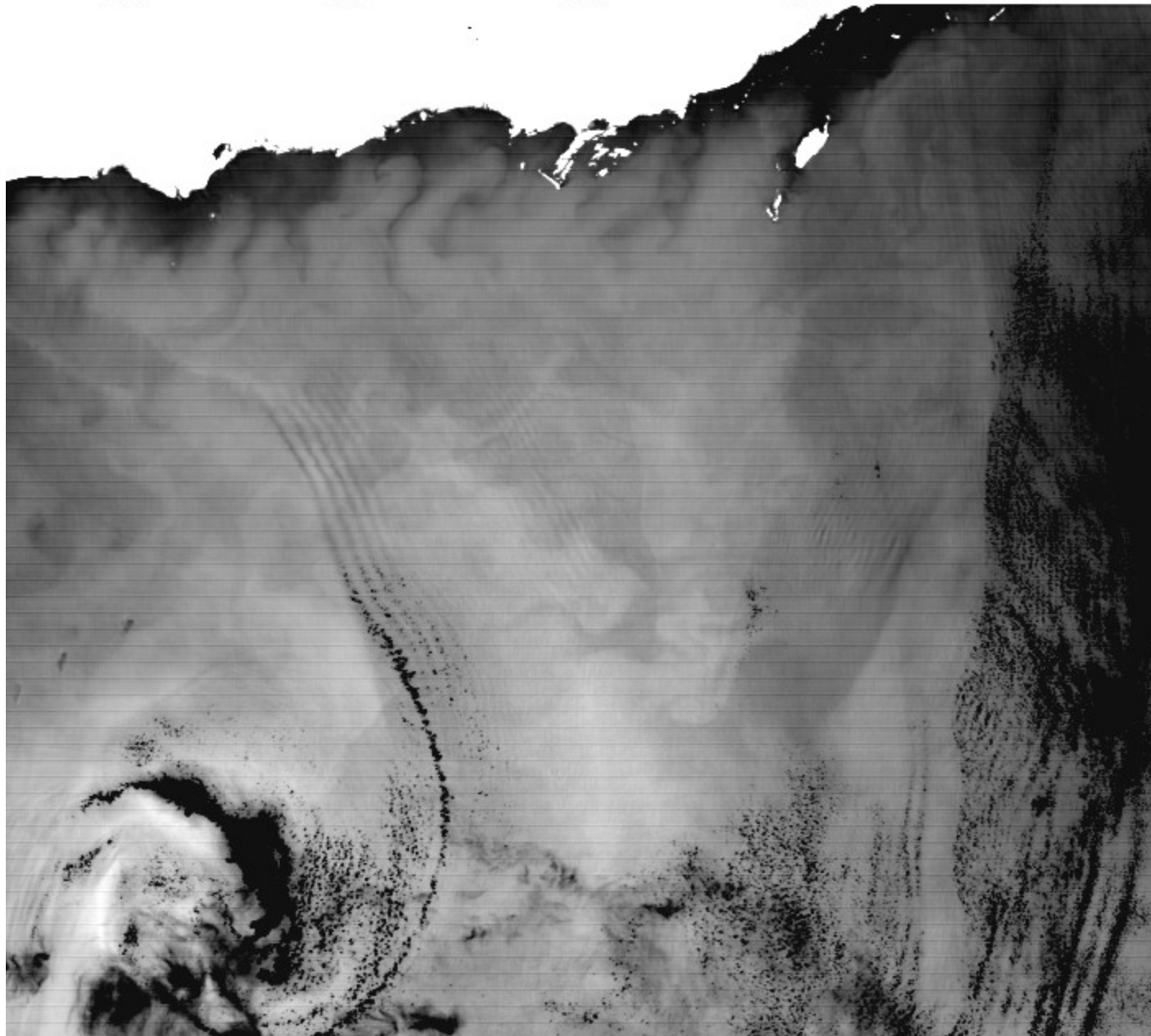
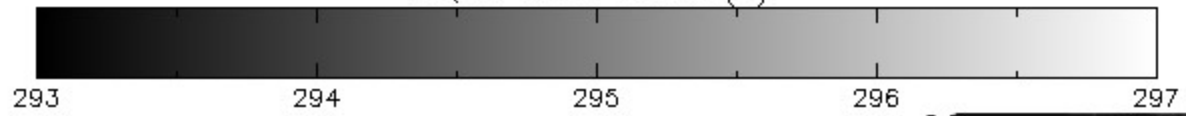
AQUA BAND 28 BT (K)



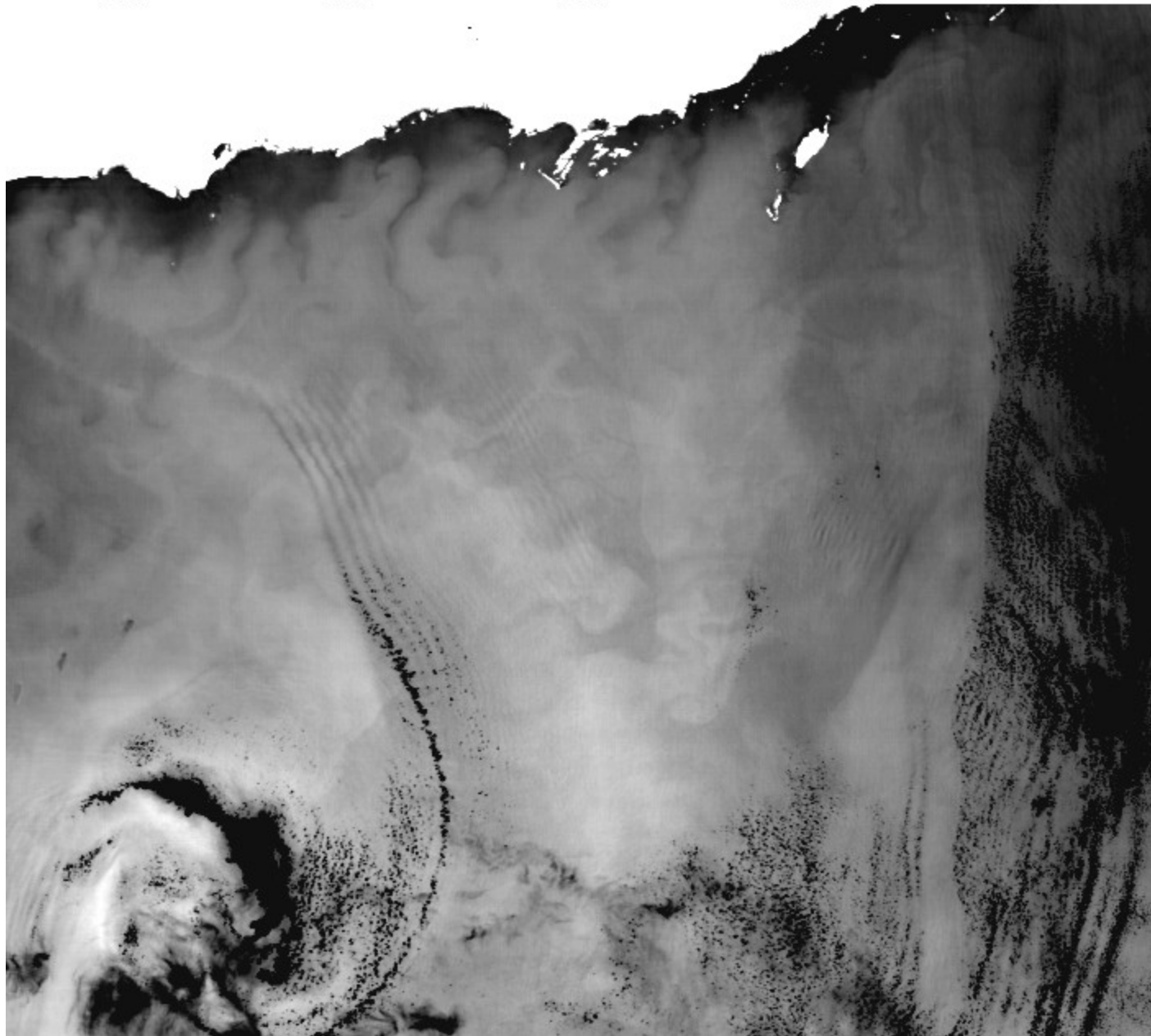
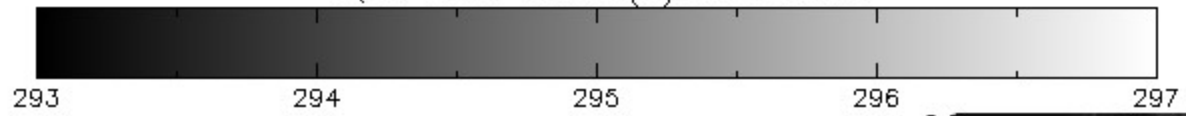
AQUA BAND 28 BT (K): DESTRIPE



AQUA BAND 29 BT (K)



AQUA BAND 29 BT (K): DESTRIPE



AQUA BAND 30 BT (K)

275

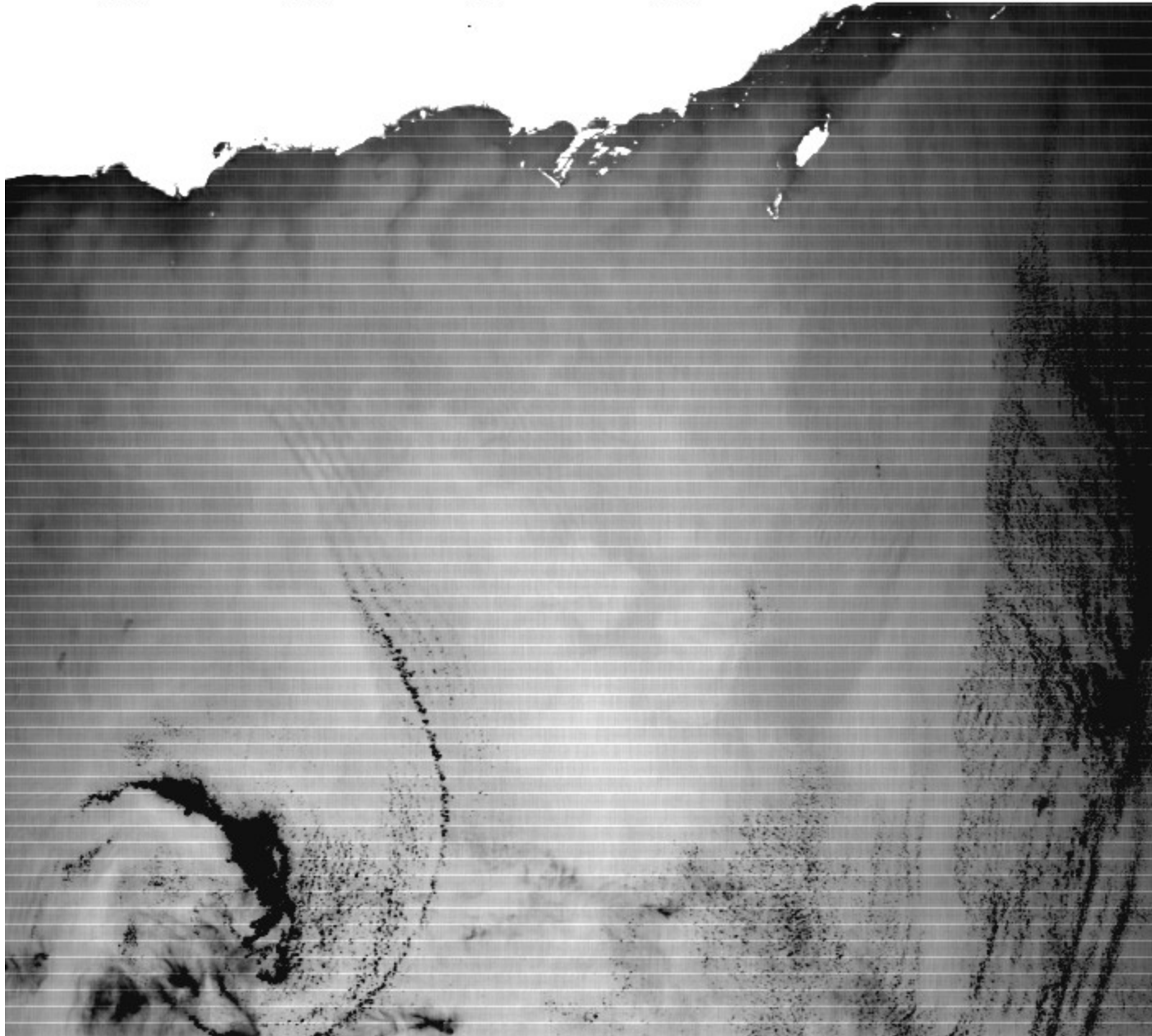
276

277

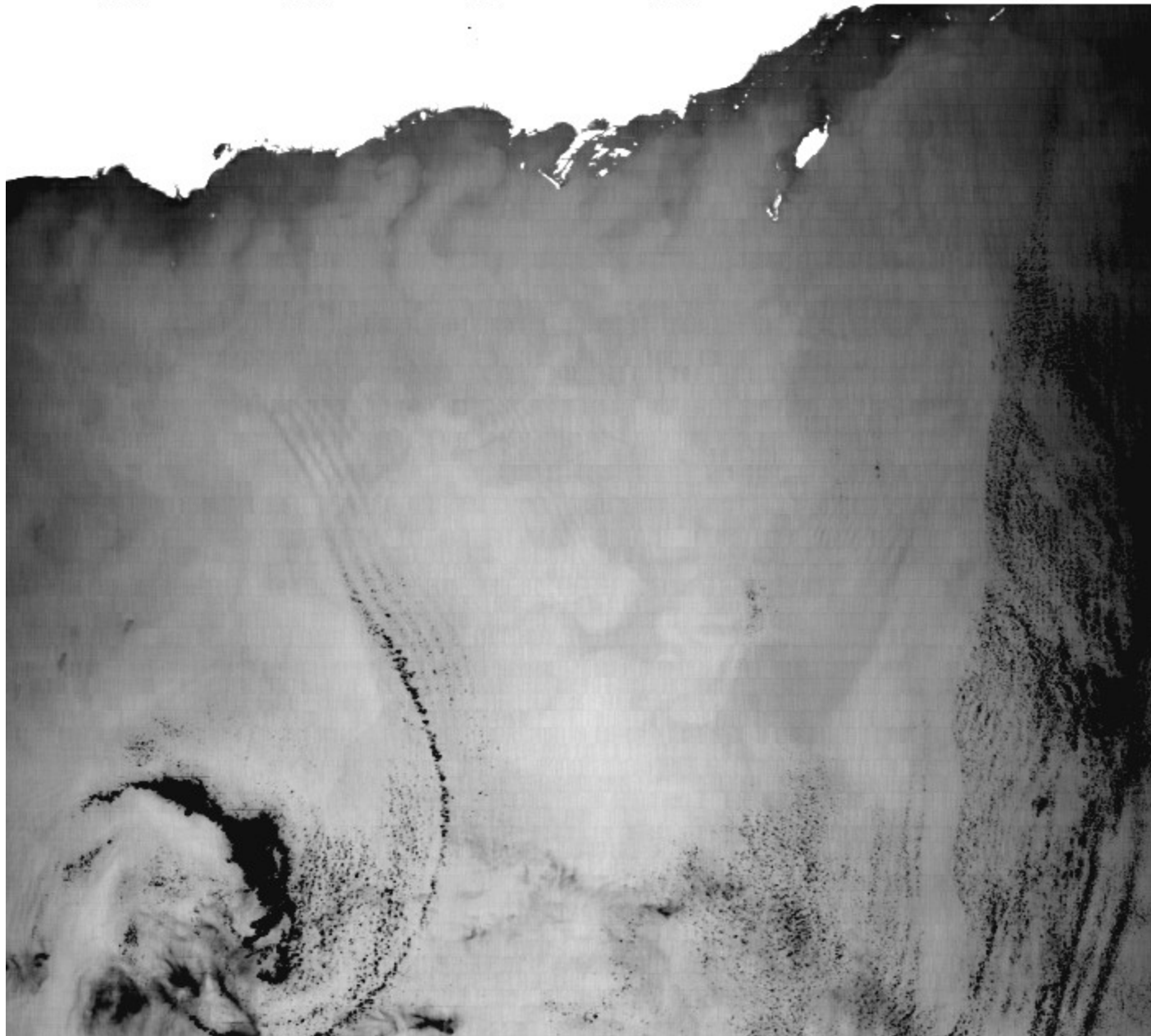
278

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AQUA BAND 30 BT (K): DESTRIPE





AQUA BAND 33 BT (K)

270

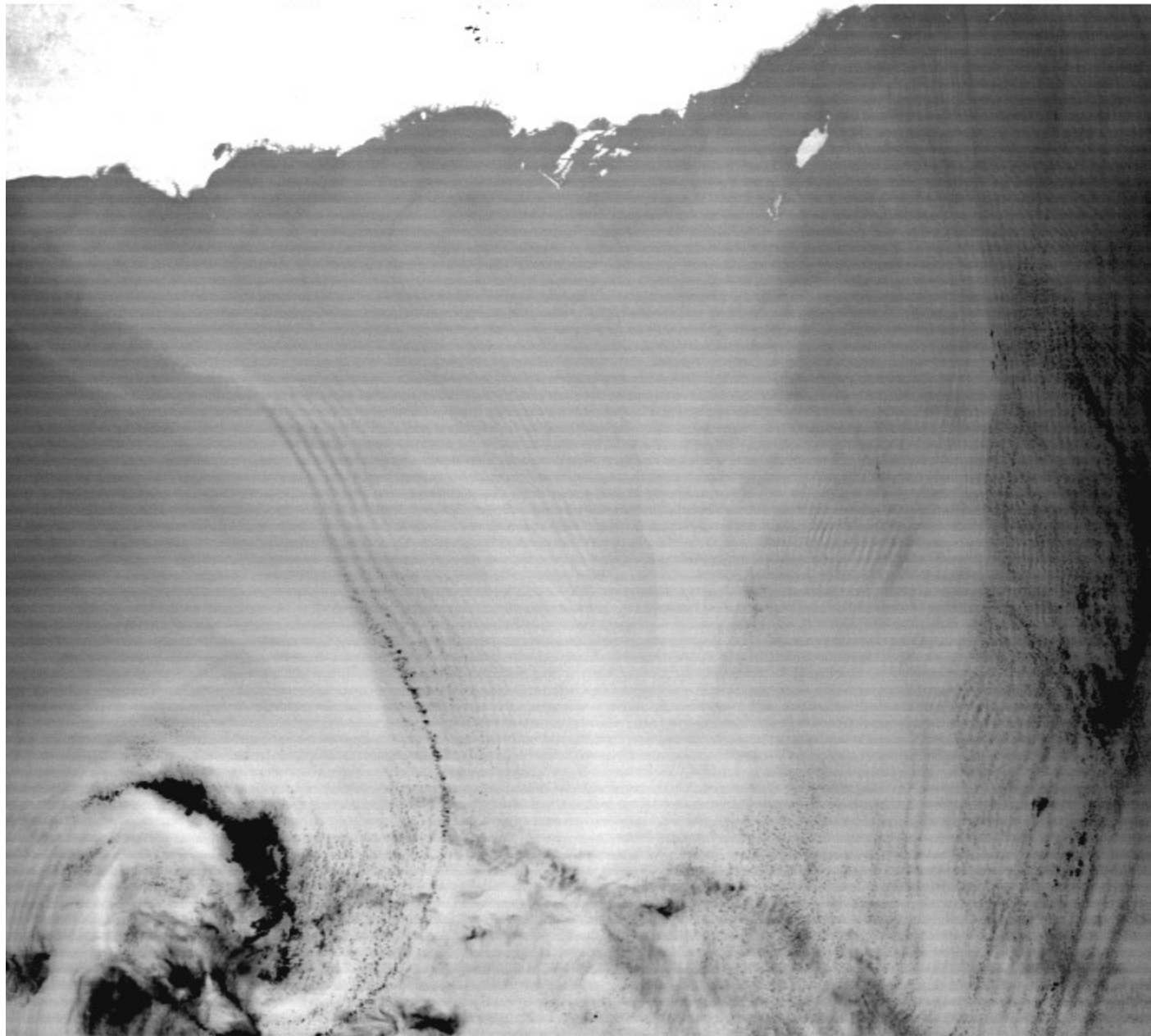
271

272

273

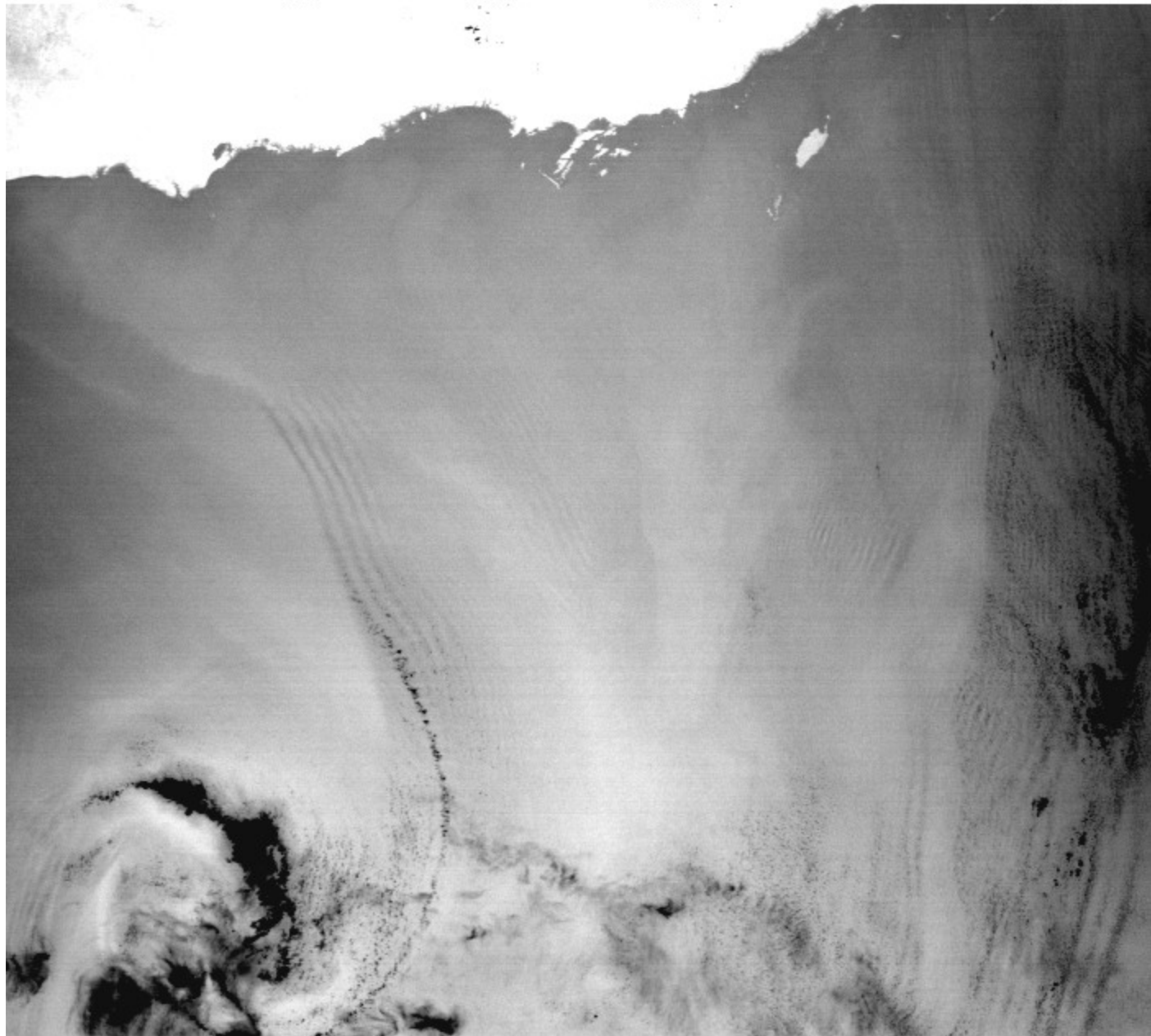
274

275





AQUA BAND 33 BT (K): DESTRIPE



AQUA BAND 34 BT (K)

258

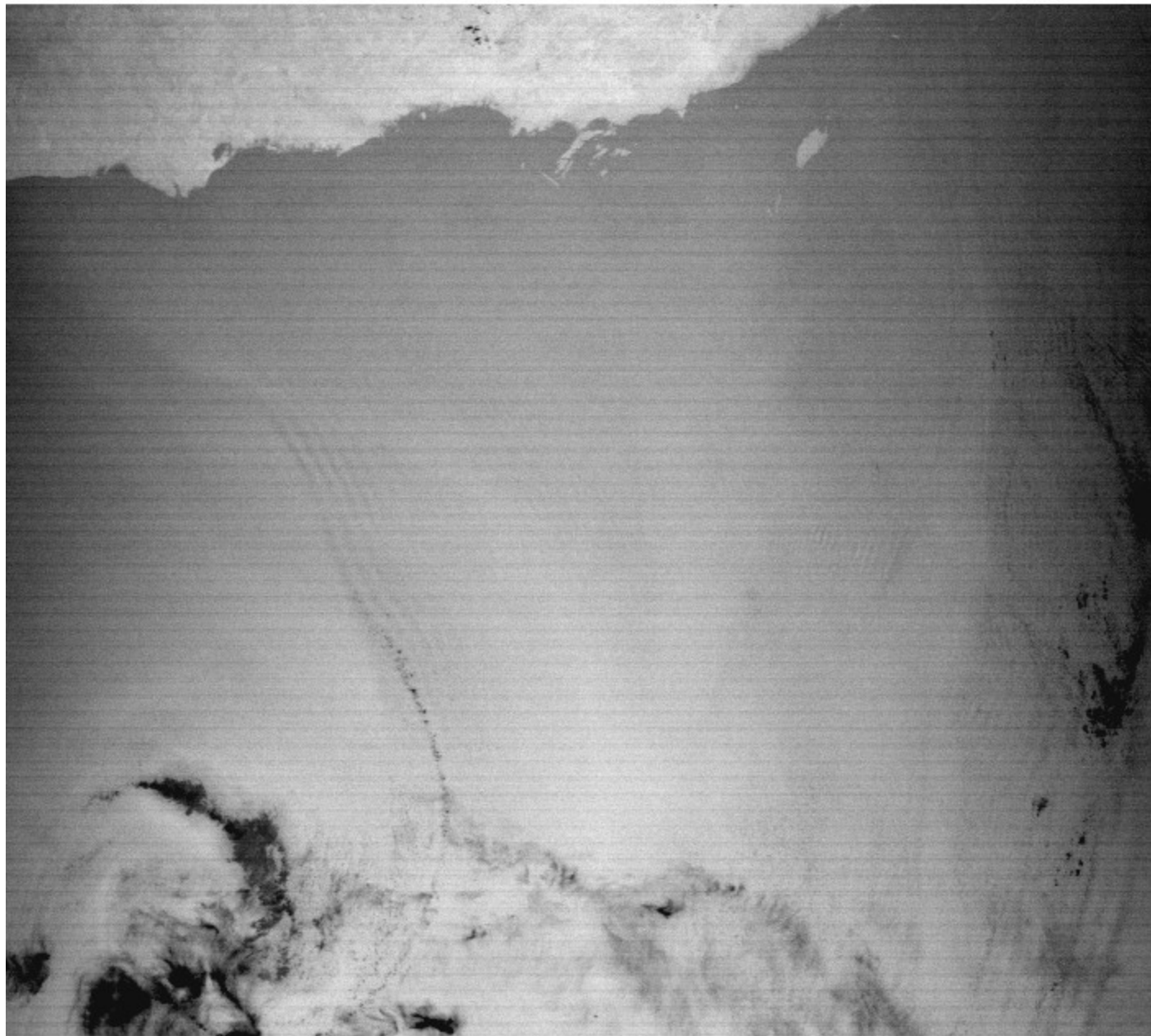
259

260

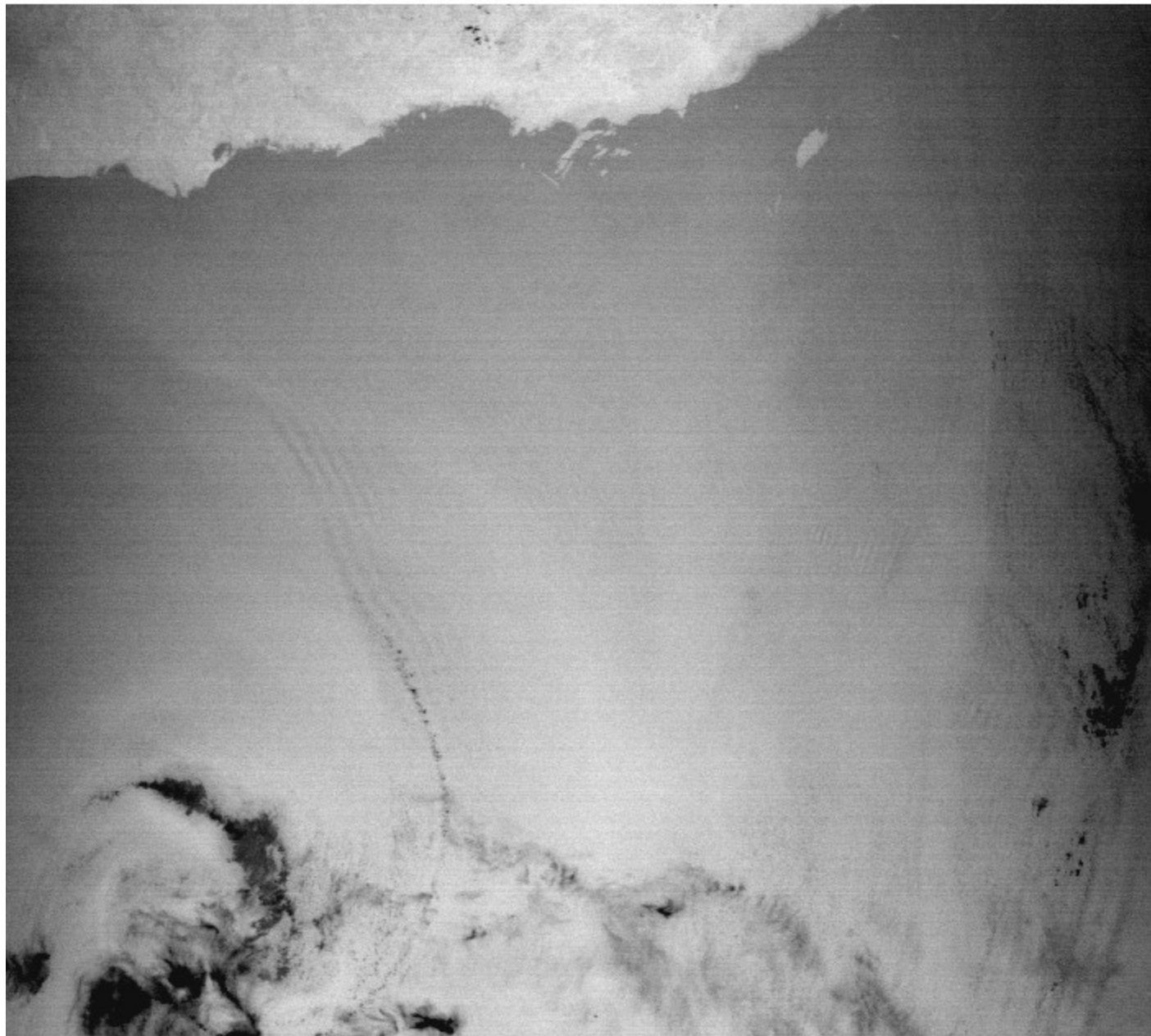
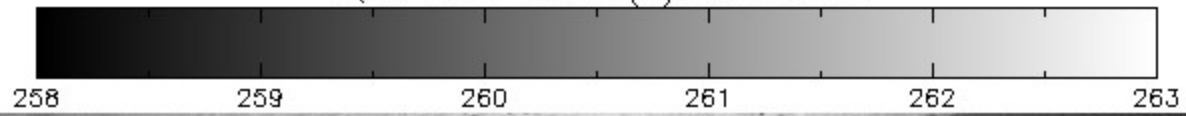
261

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AQUA BAND 34 BT (K): DESTRIPE



AQUA BAND 35 BT (K)

248

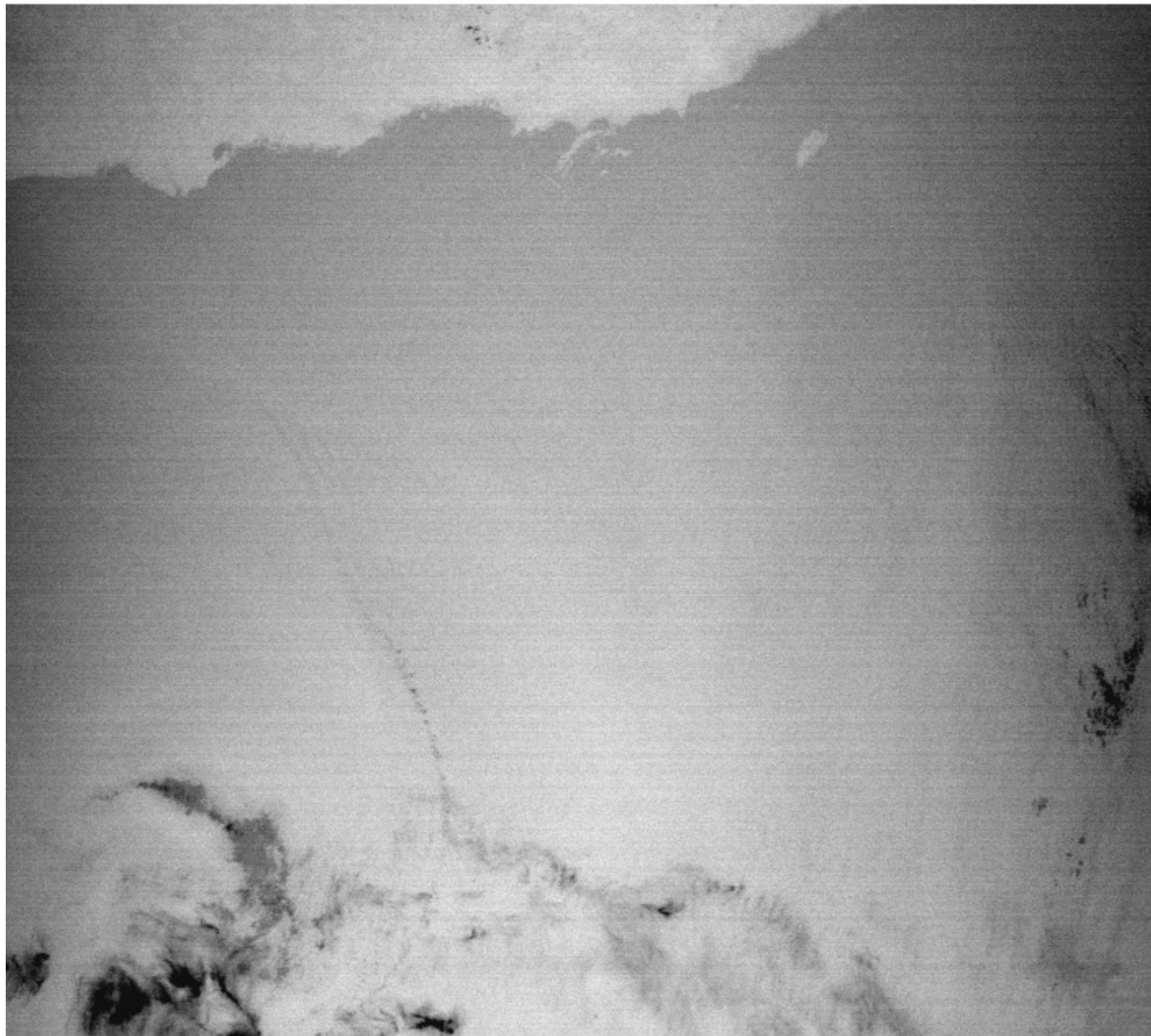
249

250

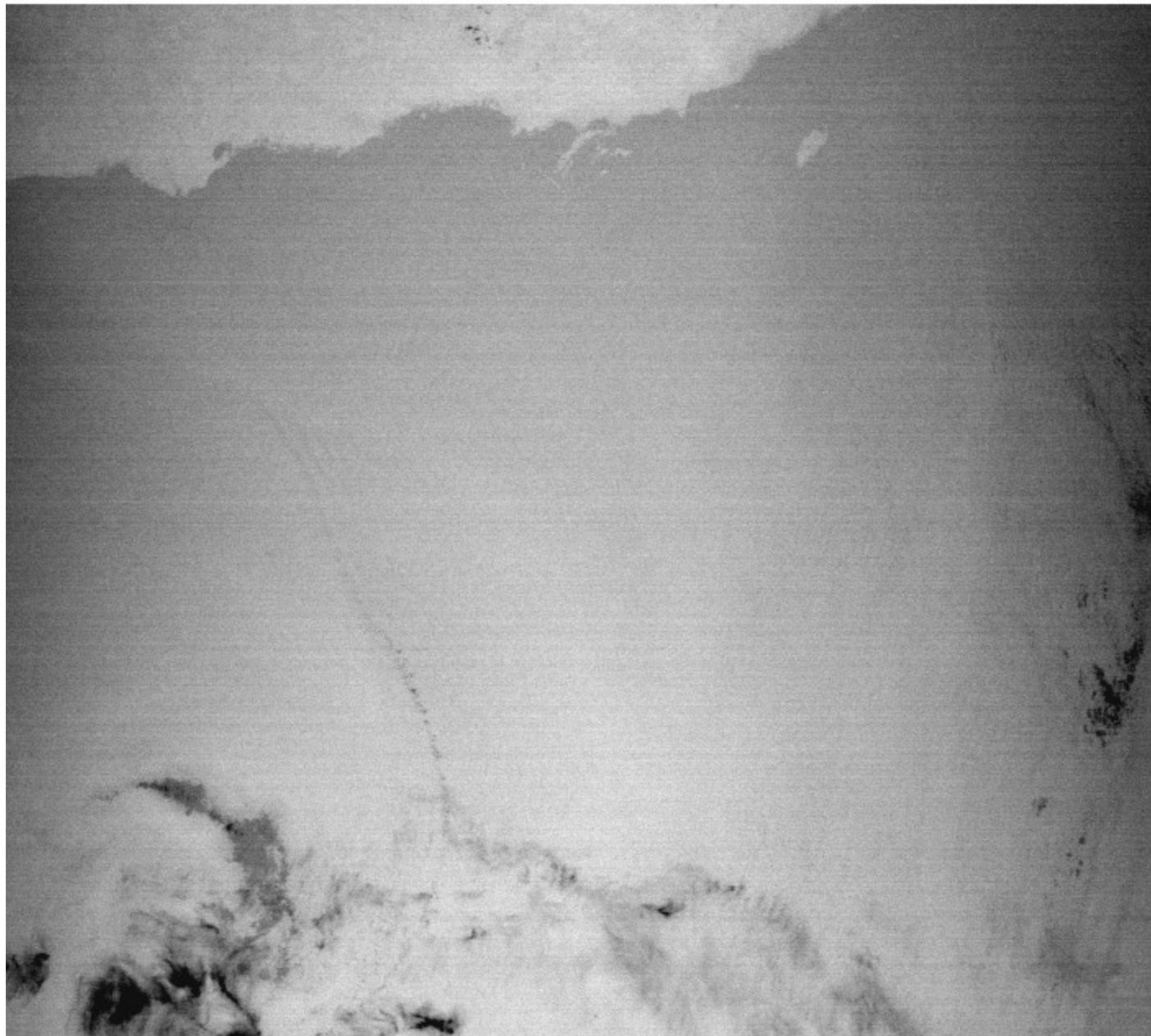
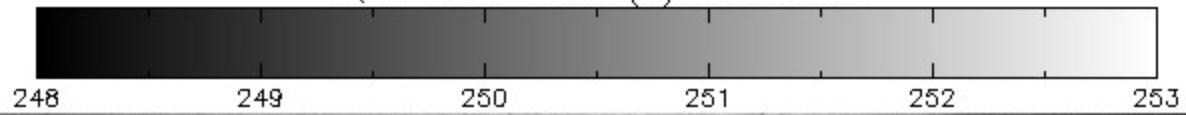
251

252

253

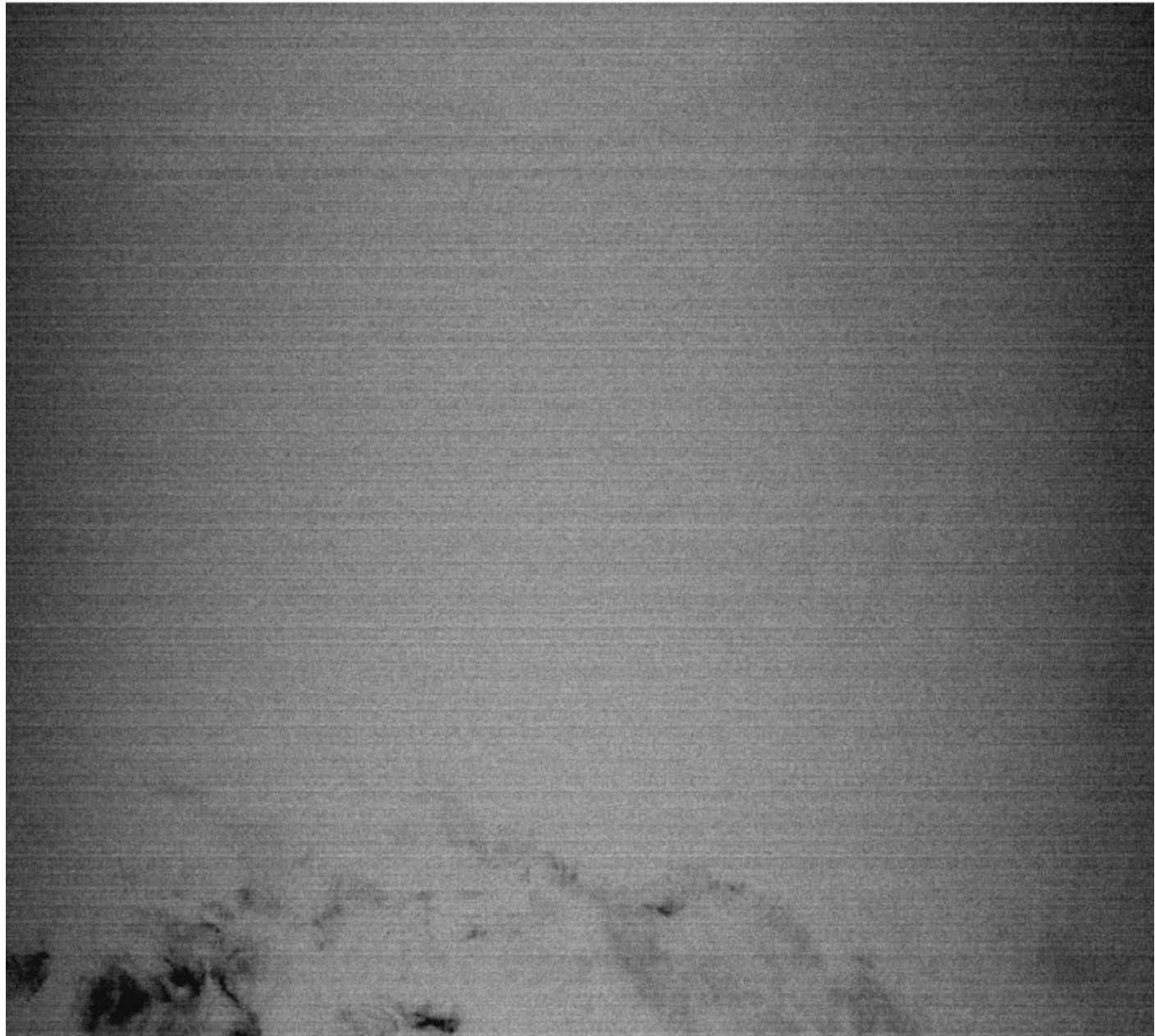


AQUA BAND 35 BT (K): DESTRIPIED

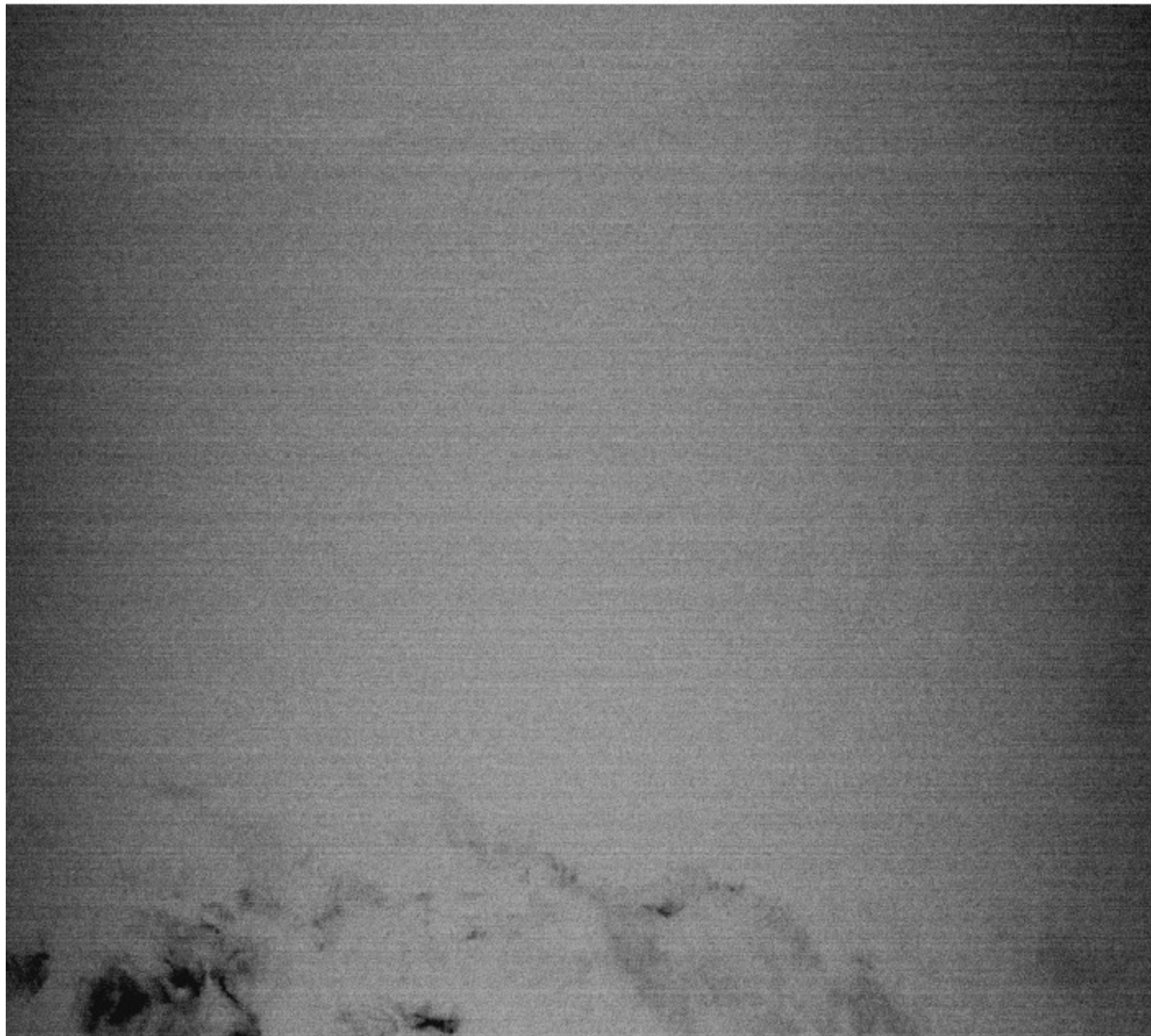
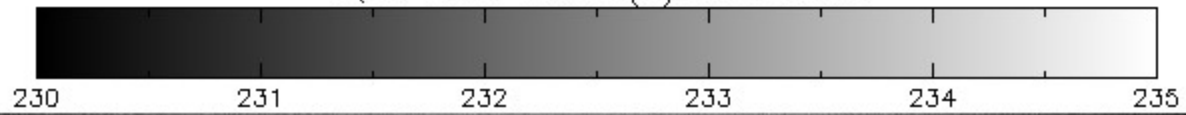




AQUA BAND 36 BT (K)



AQUA BAND 36 BT (K): DESTRIPED





# MODIS Destriping Impact on Radiometry

Analyzed an Aqua MODIS scene from 2003/10/16 19:31-19:41 UTC acquired by SSEC direct broadcast

Objective 1: Assess change in overall scene radiometry as a result of destriping (with and without median restored)

Figure 1: Histograms of (Destriped – Original) brightness temperature

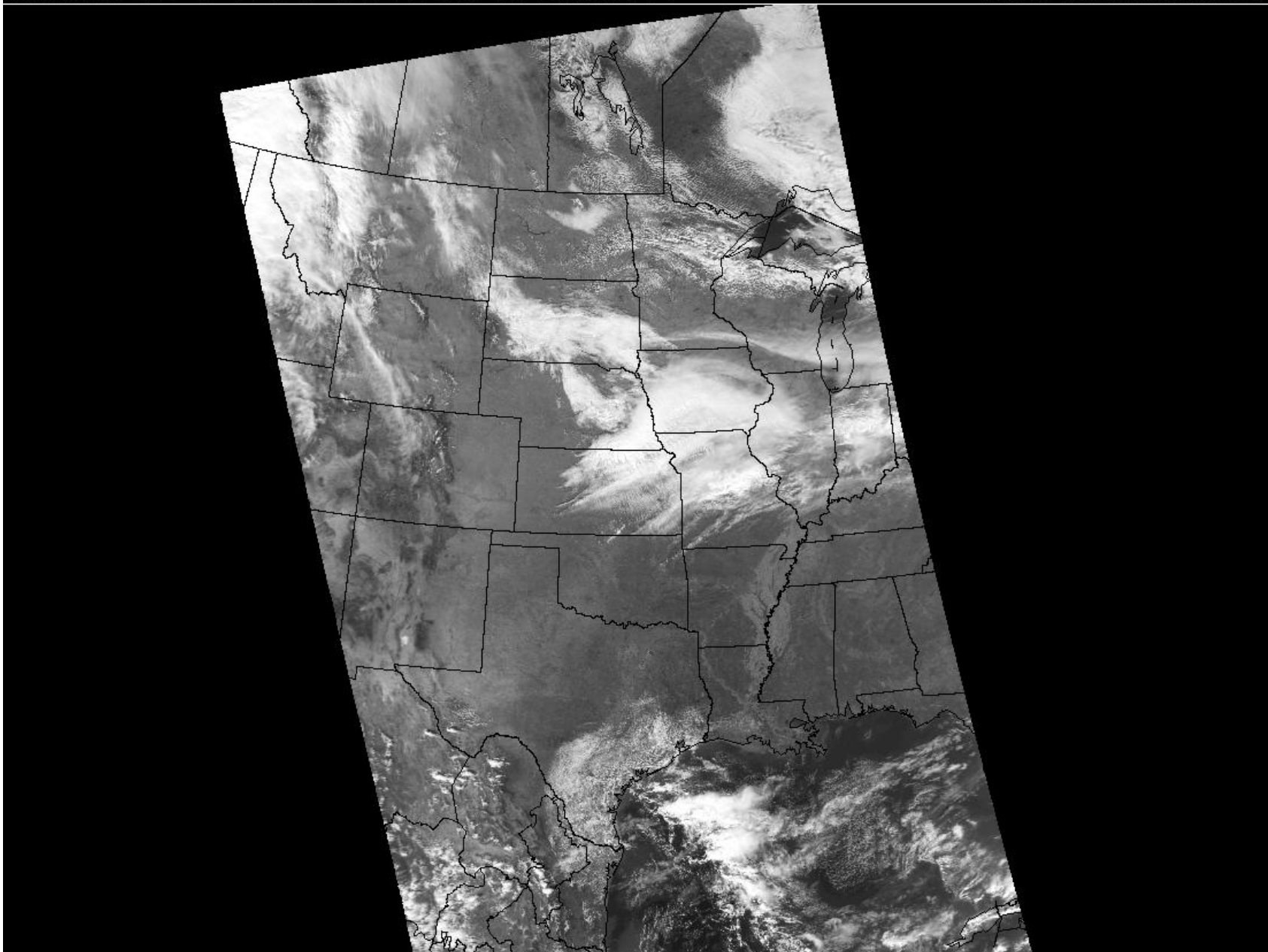
Objective 2: Assess magnitude of destriping correction as a function of scene temperature

Figure 2: Scatter plots of (Destriped – Original) brightness temperature vs. Destriped brightness temperature

# Aqua MODIS 2003/10/16 19:31-19:41 UTC

AQUA MODIS 2003-10-16 1931-1941 UTC Band 01: Continental US

SSEC UW-MADISON DIRECT BROADCAST



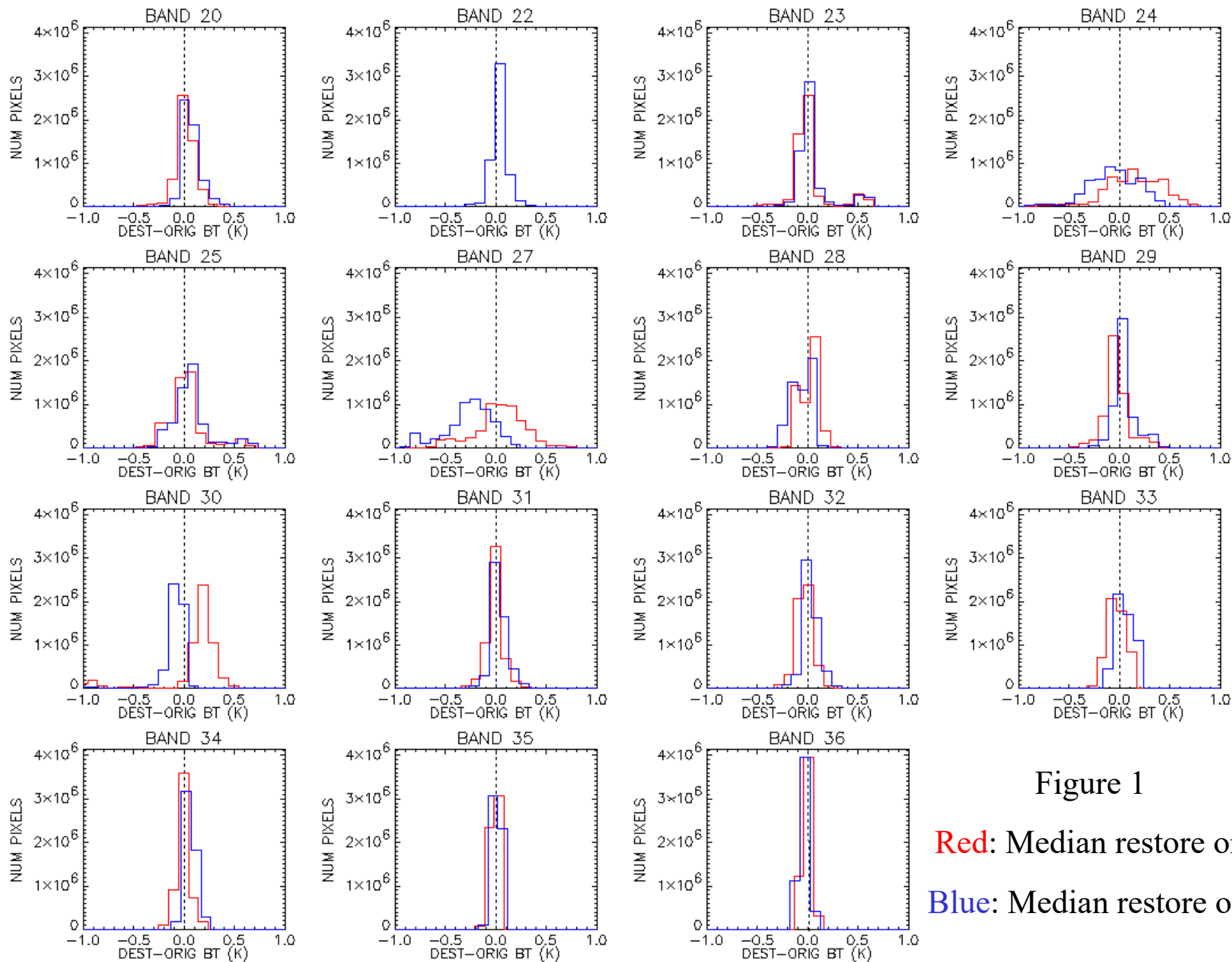


Figure 1

Red: Median restore on  
 Blue: Median restore off

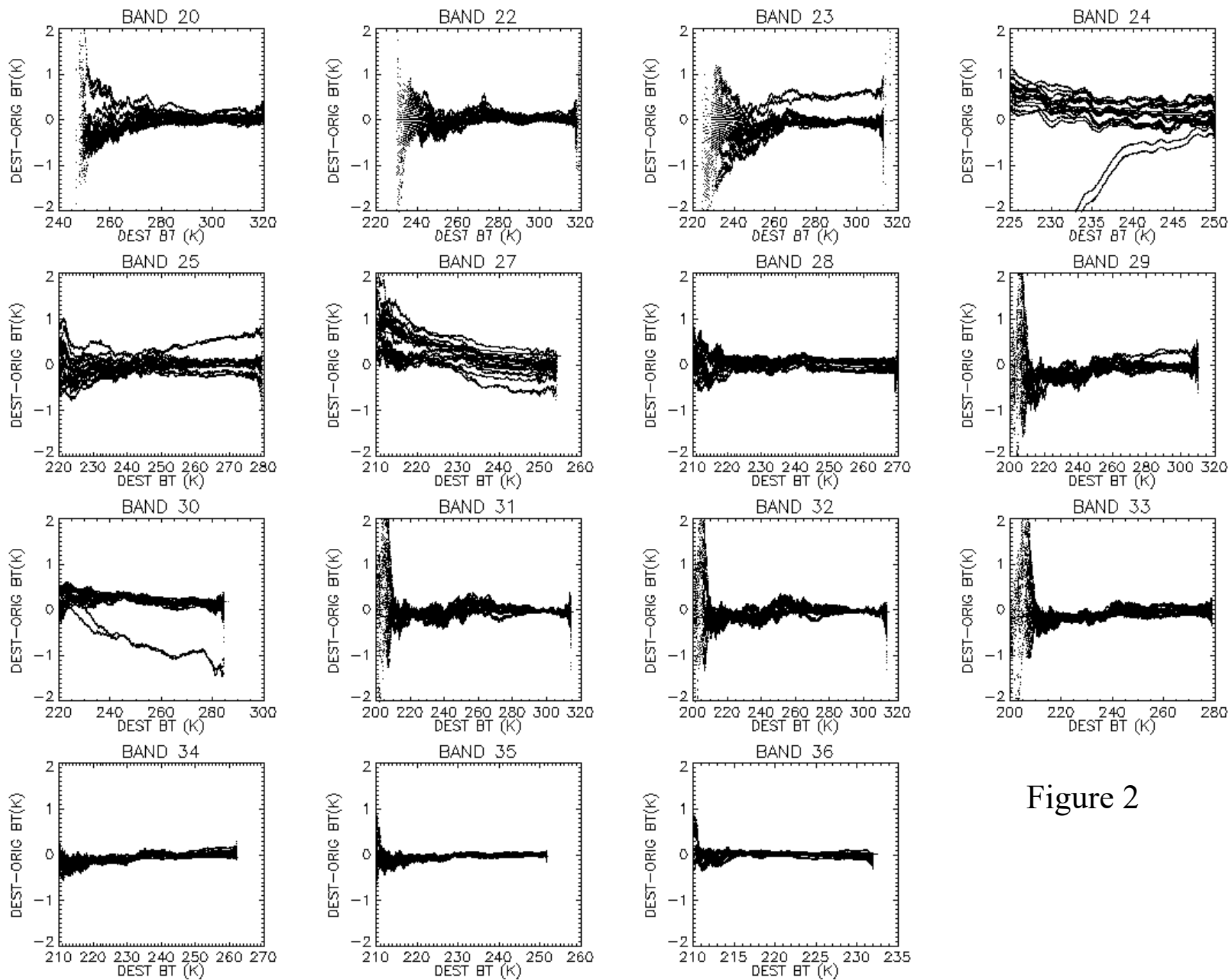


Figure 2

# MODIS Emissive Band Destriping: Granule vs. Daily Analysis

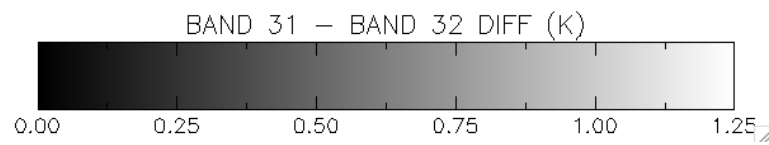
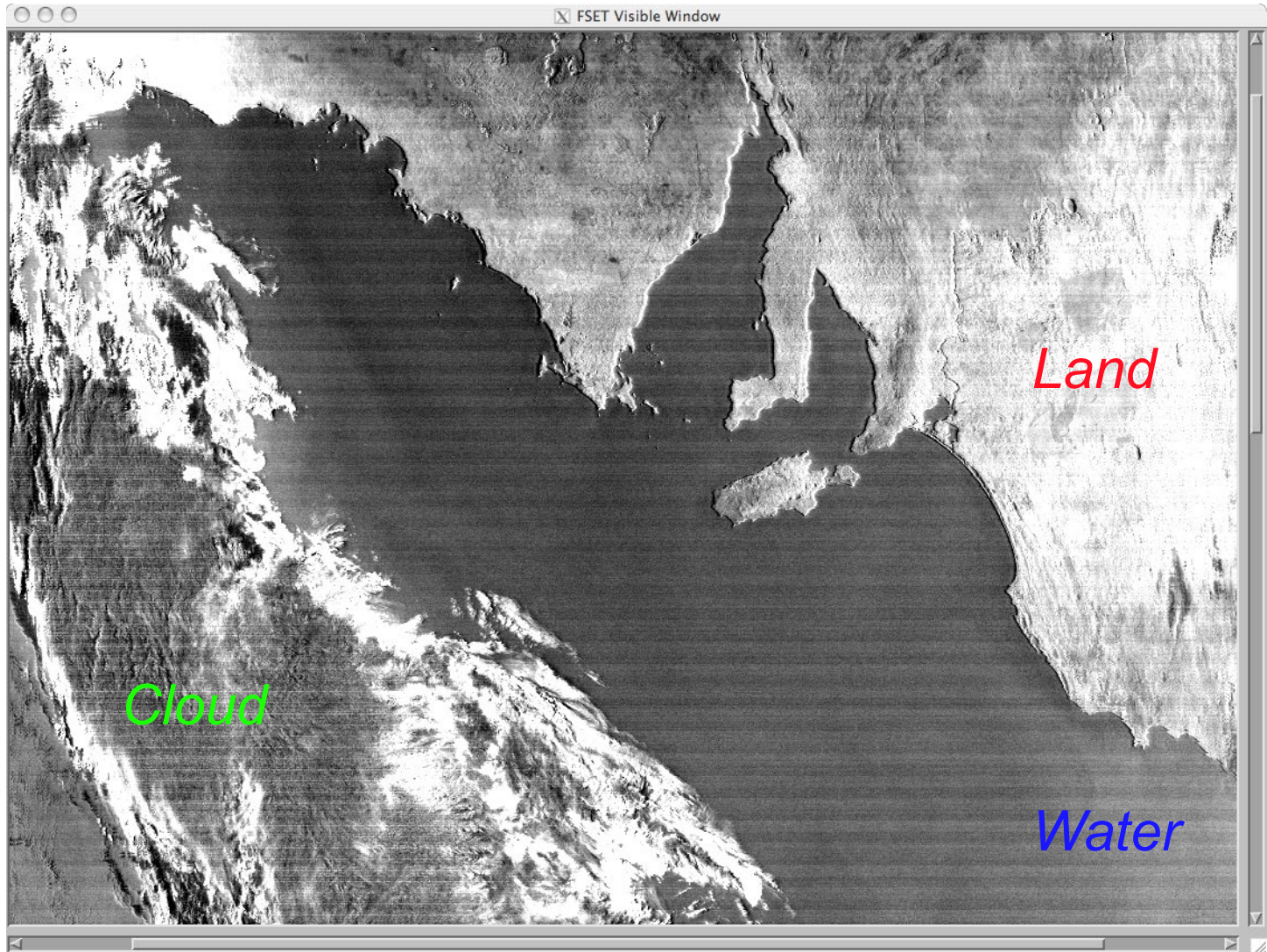
The Atmosphere Group products for collection 5 include destriping of all emissive bands (20-25, 27-36) and band 26.

The destriping algorithm is granule-based, and for a small percentage of granules, the impact may be equivocal in bands 31 and 32. Granules with sharp transitions between warm and cool scenes (e.g. hot land, cool ocean) may have artifacts in the scene transition zone.

We analyzed a complete day of data (Terra MODIS 2000337, collection 5) to develop the destriping LUT for bands 31 and 32, with the expectation that sampling a wider range of scenes would remove the artifacts.

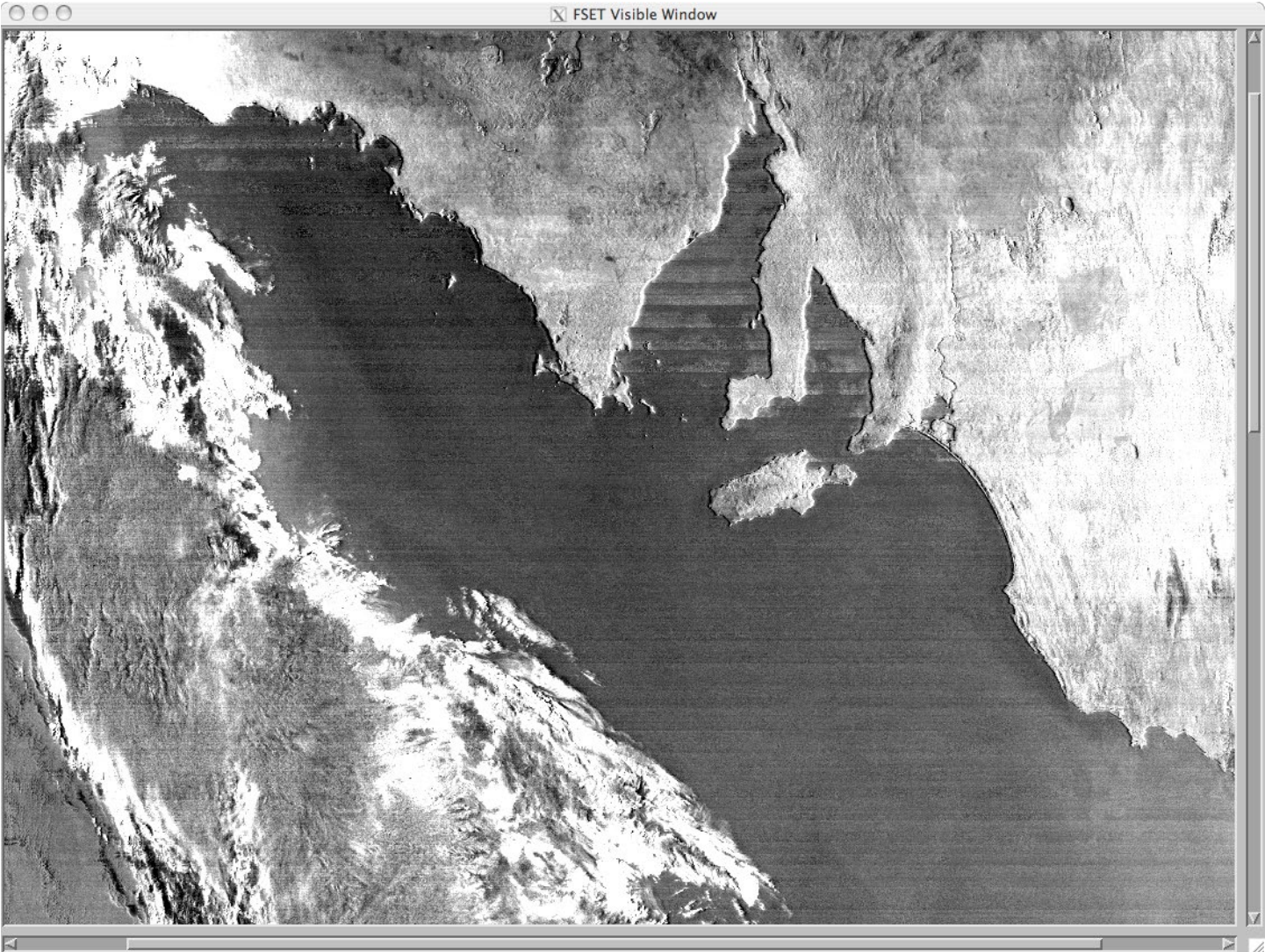


Terra MODIS 2000337 0115 UTC (South Australia)  
Band 31 - Band 32 Difference, No Destriping

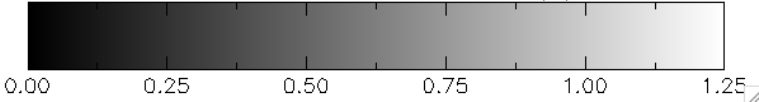




# Band 31 - Band 32 Difference, Granule-Based Destriping

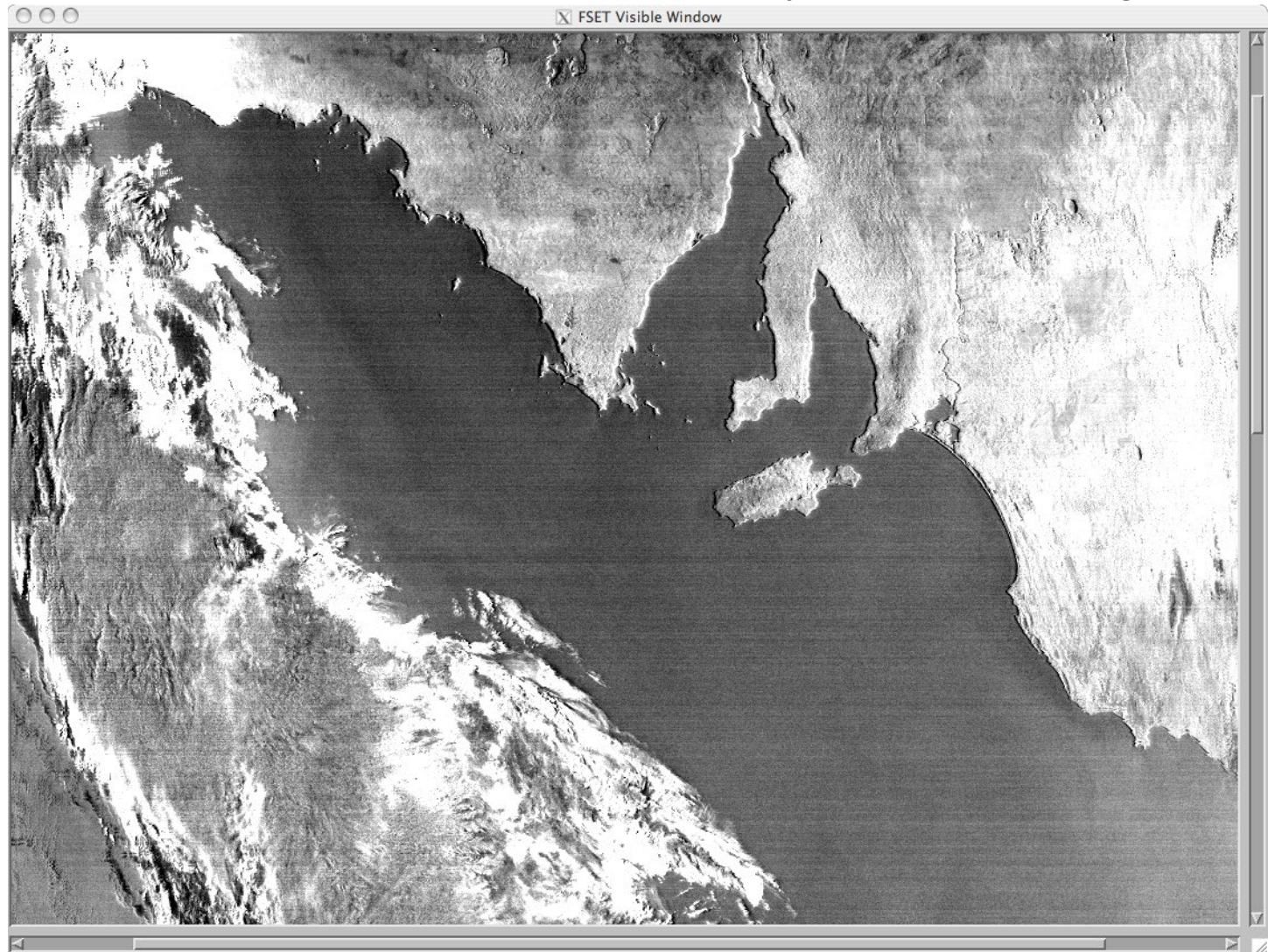


BAND 31 - BAND 32 DIFF (K)

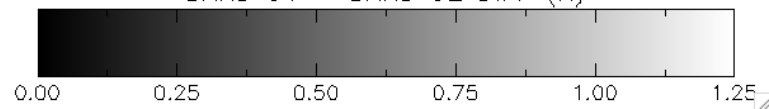




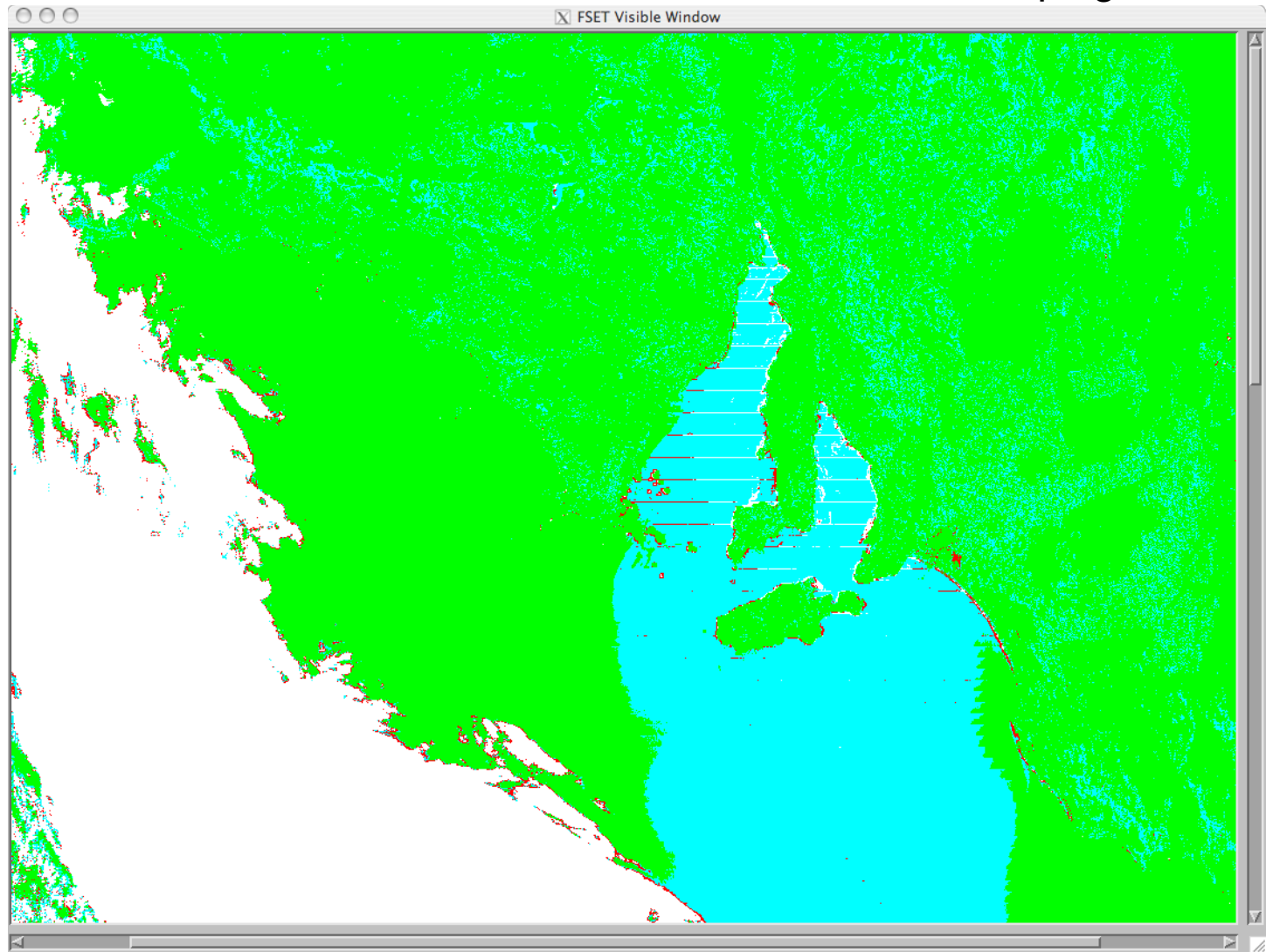
# Band 31 - Band 32 Difference, Daily-Based Destriping



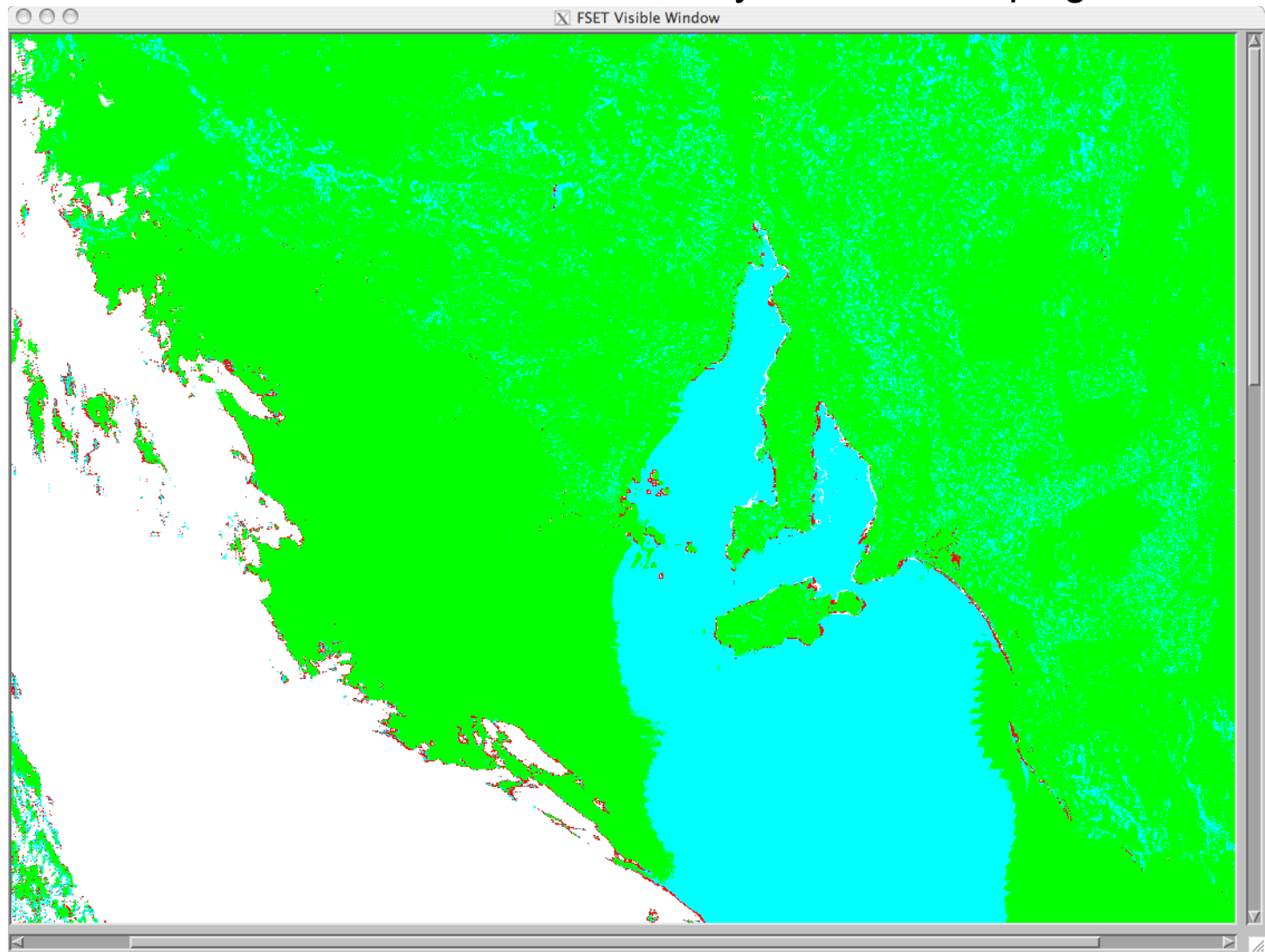
BAND 31 - BAND 32 DIFF (K)



# Cloud Mask Final Result, Granule-Based Destriping



# Cloud Mask Final Result, Daily-Based Destriping



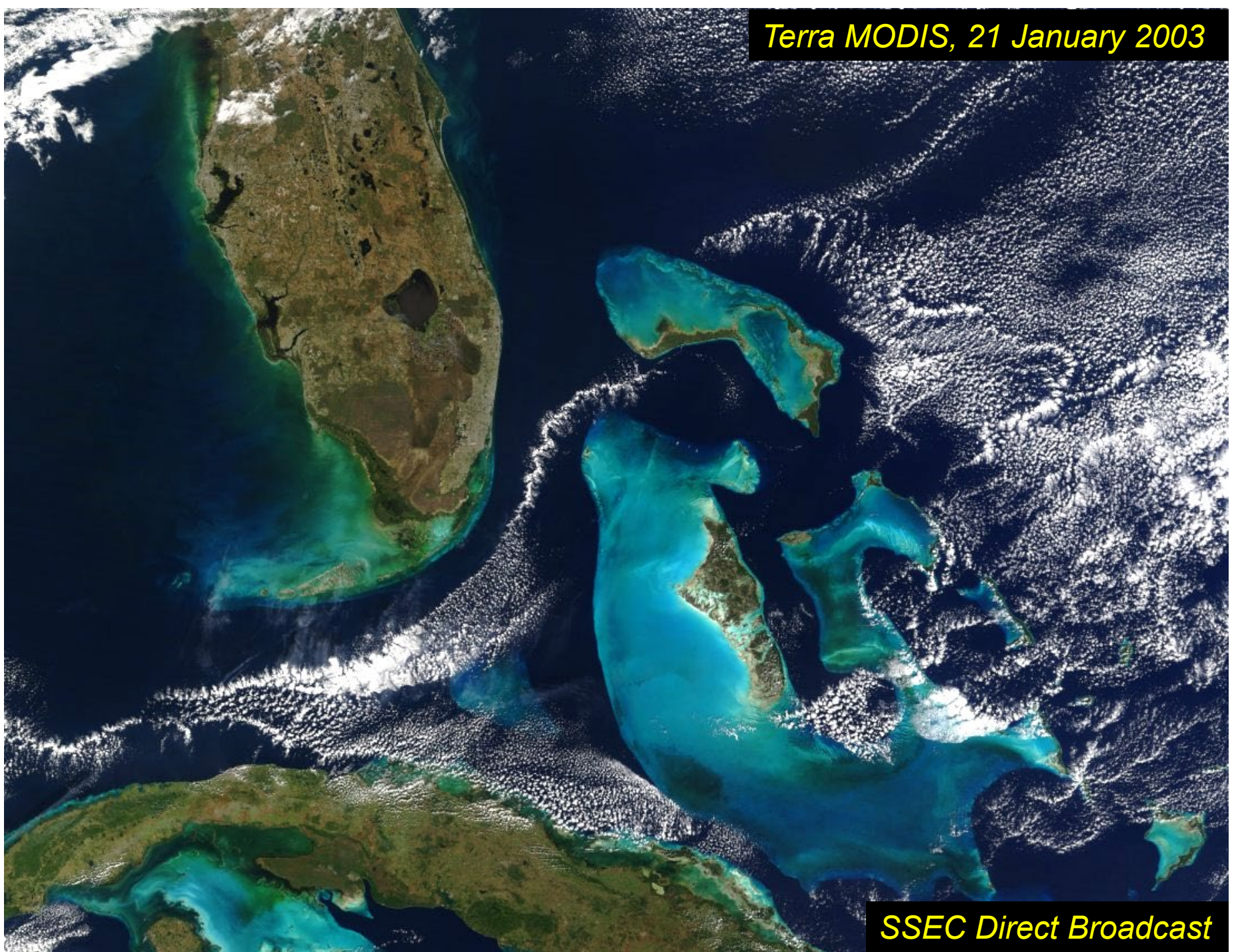
# *Creating Reprojected True Color MODIS Images*

Liam Gumley,  
Space Science and Engineering Center, Univ. of Wisconsin.

Jacques Descloitres and Jeff Schmaltz,  
NASA GSFC MODIS Rapid Response System.



*Terra MODIS, 21 January 2003*



*SSEC Direct Broadcast*



*MODIS 250 meter natural color*



# Why Reprojection?

Reasons why reprojection is desirable:

1. Removes Bowtie Artifacts
2. Allows geographic overlays (e.g. coastline, city locations)
3. Makes pretty pictures for publication on the web or in print
4. Allows collocation with other sensors or measurements
5. Prepares for ingest into GIS (e.g., GeoTIFF)

Good reprojection software is hard to find!

- Needs to understand MODIS format
- Should handle a variety of common projections
- Should be relatively easy to use and well documented
- Batch processing is a bonus
- Zero cost (i.e., free) is the icing on the cake



# Software for Reprojecting MODIS Images

MRTSwath: MODIS Swath Reprojection Tool (*Free*) ★ ★ ★ ★ ★

<http://edcdaac.usgs.gov/landdaac/tools/mrtswath/>

MS2GT: MODIS Swath to Grid Toolkit (*Free*) ★ ★ ★ ★ ★

<http://cires.colorado.edu/~tharan/ms2gt/>

HDFLook-MODIS (*Free*) ★ ★ ★ ★

[http://www-loa.univ-lille1.fr/Hdflook/hdflook\\_gb.html](http://www-loa.univ-lille1.fr/Hdflook/hdflook_gb.html)

ENVI: Environment for Visualizing Images (\$\$\$) ★ ★ ★

<http://www.rsinc.com/envi/>

HEG: HDF-EOS to GeoTIFF converter (*Free*) ★ ★

<http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html>

# MODIS L1B Reprojection Software Features

<i>Software</i>	<i>UNIX</i>	<i>Windows</i>	<i>GeoTIFF output</i>	<i>Batch operation</i>	<i>Output quality</i>	<i>Cost</i>
MRTSwath	Yes	Yes	Yes	Yes	Excellent	Free
MS2GT*	Yes	No	Yes	Yes	Excellent	Free
HEG	Yes	Yes	Yes	Yes	Fair	Free
HDFLook-MODIS	Yes	Yes	Yes	Yes	Good	Free
ENVI	Yes	Yes	Yes	?	Fair	\$\$\$

\* MS2GT requires IDL

# Why True Color Images?

- Dramatic impact (more so than single band images)
- Excellent for public relations purpose
- Require comparatively little explanation
- Can use as base for displaying other products (e.g. fires)
- Daily 250 meter images in near real time are a first!

MODIS True Color Galleries:

<http://rapidfire.sci.gsfc.nasa.gov/gallery/>

[http://www.ssec.wisc.edu/~gumley/modis\\_gallery/](http://www.ssec.wisc.edu/~gumley/modis_gallery/)



# Eastern China



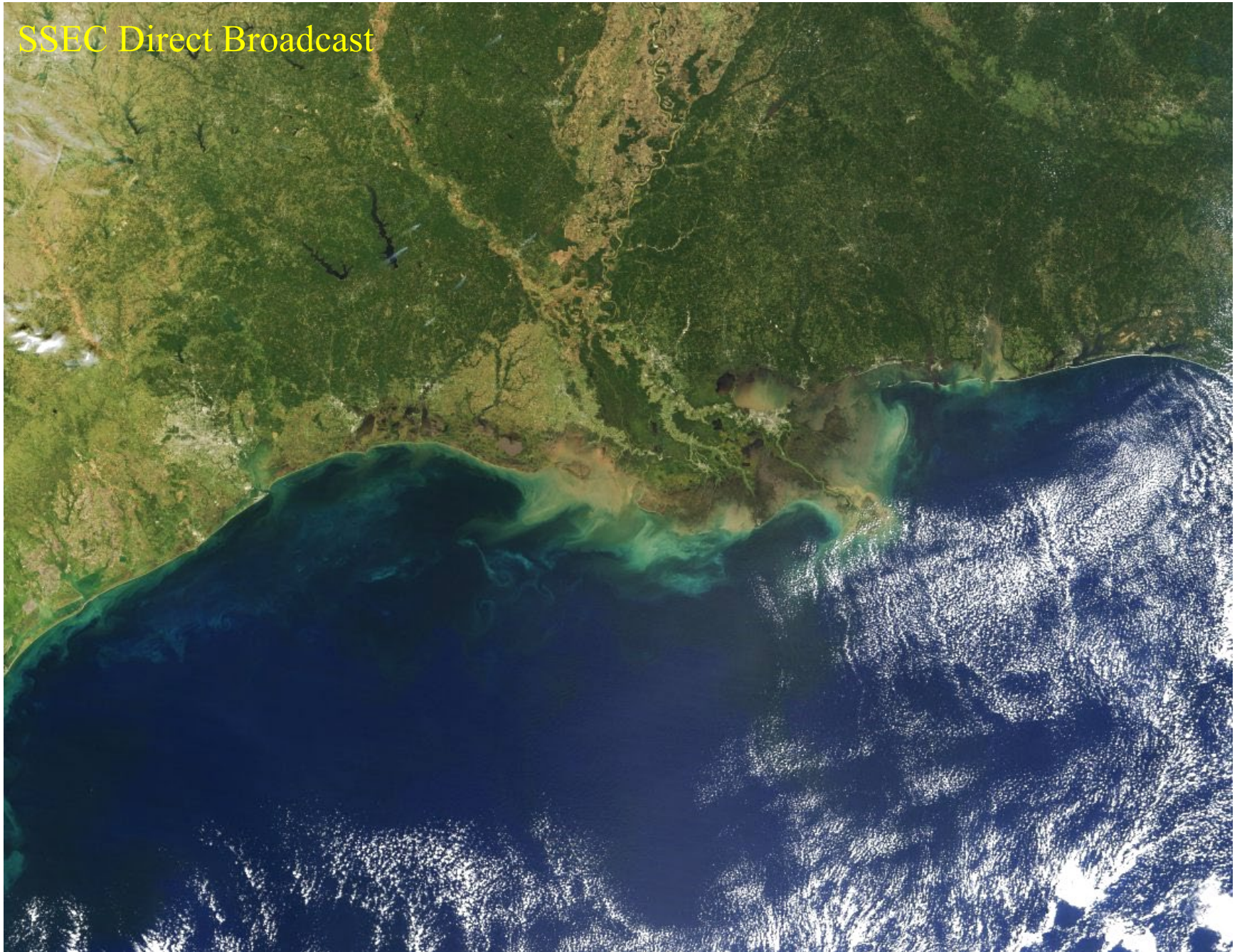






# Mississippi Delta, Louisiana

SSEC Direct Broadcast



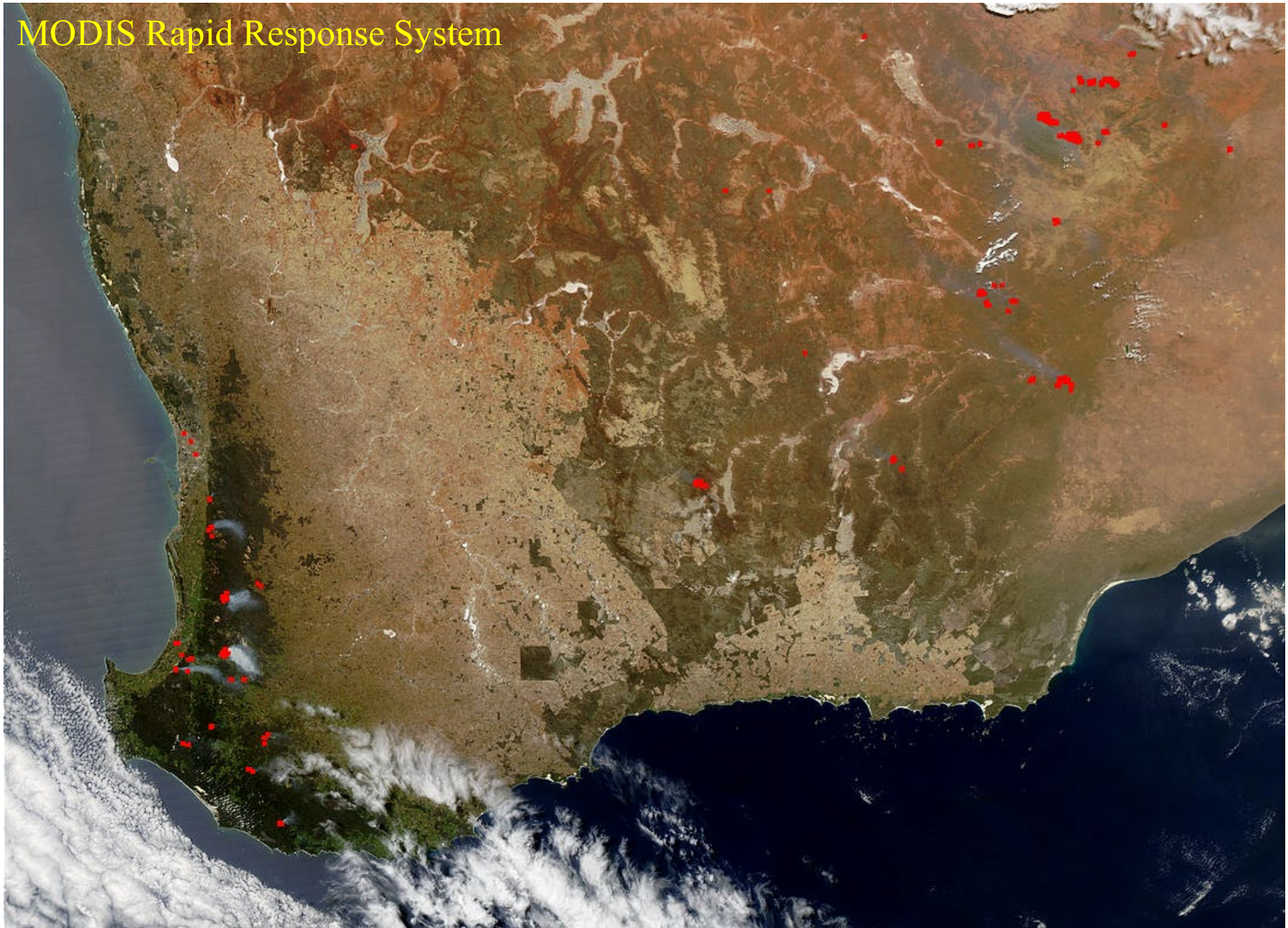




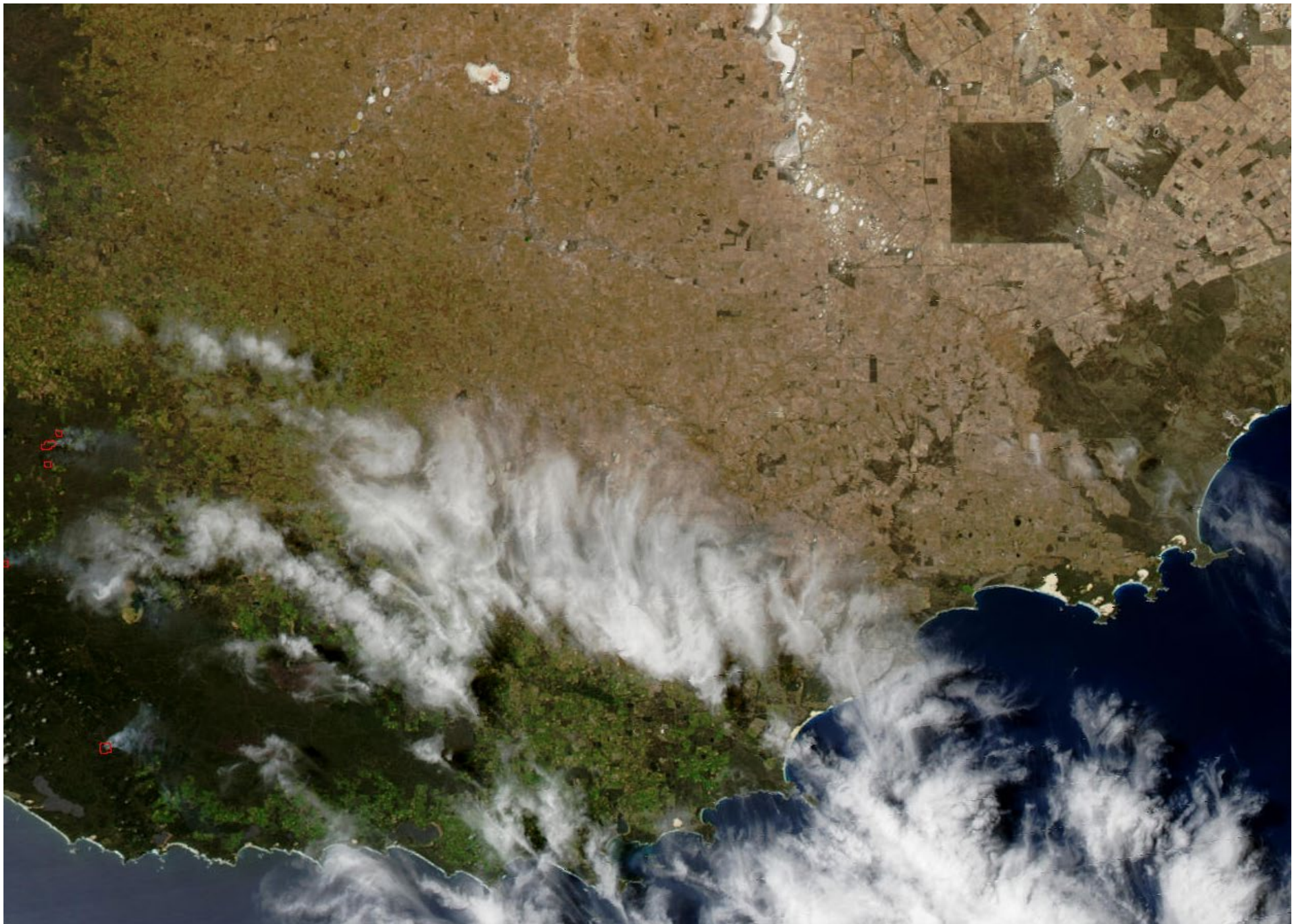


# Southwest Western Australia

MODIS Rapid Response System







# True Color Bands and Resolution

- Use bands 1, 4, 3 (0.65, 0.55, 0.47  $\mu\text{m}$ ) for red, green, blue because of wide dynamic range.
- Band 1 is 250 meter native resolution; bands 3 and 4 are 500 meter native resolution.
- Can use the image data for input at 1000, 500, or 250 meter resolution.
- Choice of output resolution for reprojected images is up to the user (e.g., 8 or 4 km for continental, 2 or 1 km for state, 500 or 250 meter for high resolution scenes). Output resolution does not have to match the input resolution.
- Must use accurately interpolated geolocation data for reprojected images.

## Tutorial Details

- Designed to run on UNIX systems (including Linux)
- Uses freely available software (no need to buy anything)
- Works with MODIS L1B 1KM, HKM, and QKM resolution data from Terra and Aqua
- Tutorial document (PDF), source code, sample data:

<ftp://ftp.ssec.wisc.edu/pub/IMAPP/MODIS/TrueColor/>

# Software Required for Tutorial

MODIS Corrected Reflectance

<http://directreadout.gsfc.nasa.gov/>

MODIS Swath to Grid Toolbox (MS2GT)

<http://nsidc.org/data/modis/ms2gt/>

IDL

<http://www.rsinc.com/>

Note: License is *not* required: can use IDL 6.0 Virtual Machine

Image Magick

<http://www.imagemagick.org/>

## Required Input Data

MODIS Level 1B radiance files at 1000, 500, and 250 meter resolution (Terra or Aqua)

*and*

MODIS Level 1B geolocation file at 1000 meter resolution

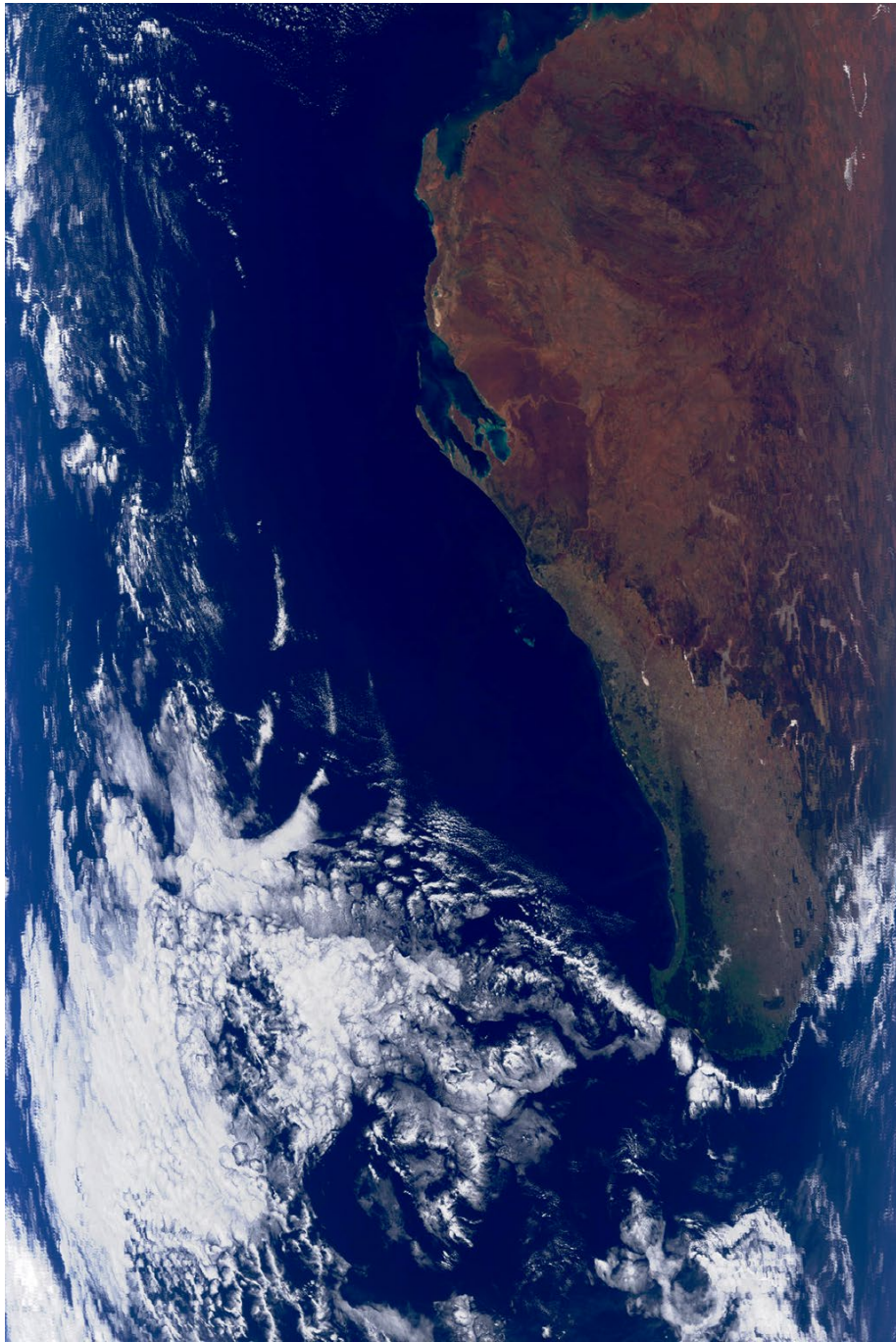
***IMAPP or DAAC L1B format may be used!***

# Corrected Reflectance Algorithm

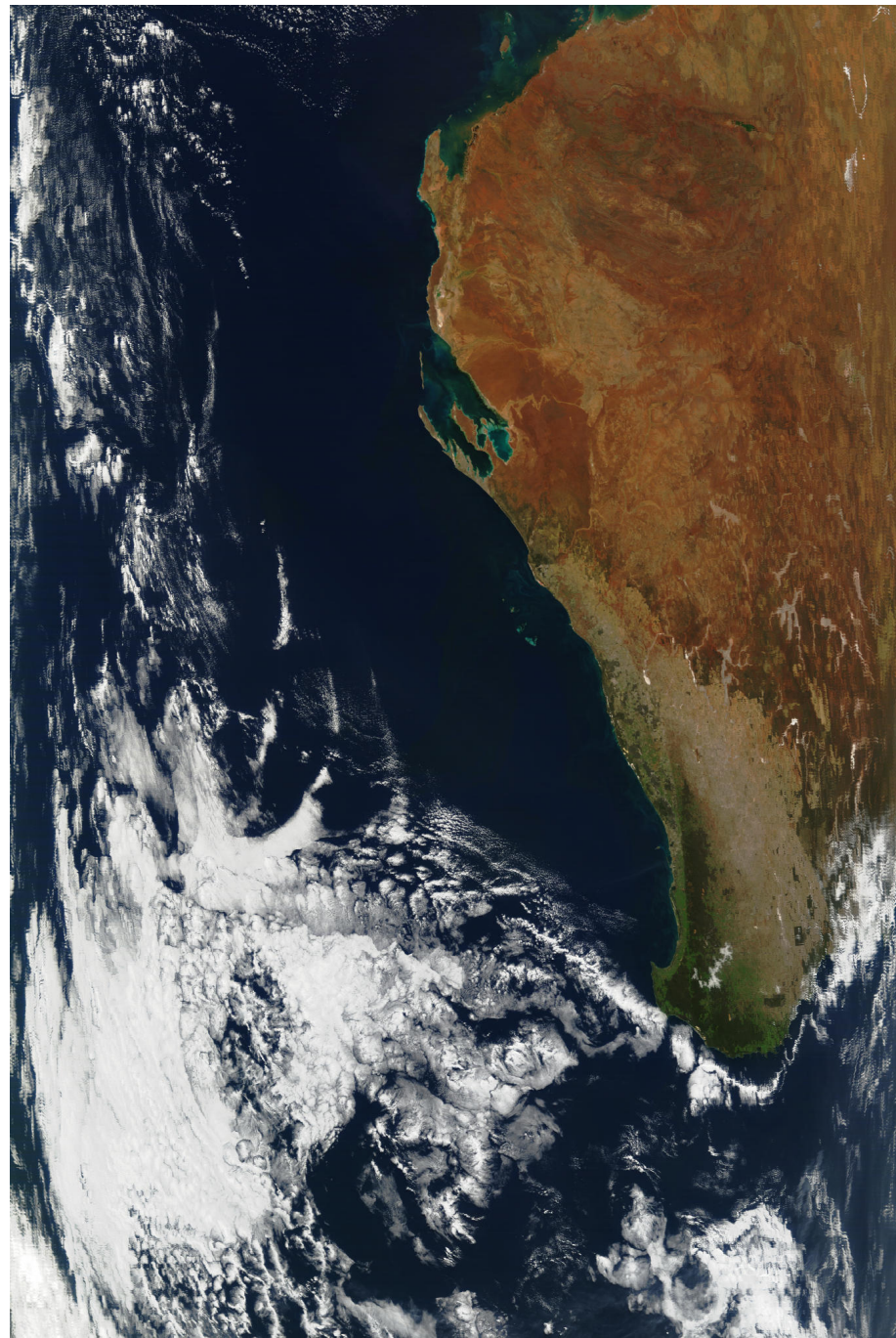
- Developed by Jacques Descloitres for MODIS Rapid Response System
- Designed to provide natural looking true color images.
- Removes Rayleigh scattering and accounts for absorption by ozone, oxygen, and water vapor in conjunction with a low resolution terrain database. No correction for aerosol.
- Removes haze from blue band.
- Is similar to the MODIS surface reflectance product MOD09, except that it does not correct for aerosols.



TOA reflectance



Corrected reflectance



# Corrected Reflectance Script

```
#!/bin/csh
# Check the input arguments
if ($#argv != 4) then
    echo "Usage: Crefl.csh MOD01KM MOD02HKM MOD02QKM MOD03"
    exit(1)
endif
echo "(Creating MODIS corrected reflectance)"
ln -f -s $1 MOD021KM.hdf
ln -f -s $2 MOD02HKM.hdf
ln -f -s $3 MOD02QKM.hdf
ln -f -s $4 MOD03.hdf
setenv ANCPATH $HOME/NDVI/run
$HOME/NDVI/NDVI.src/crefl -f -v -1km \
    MOD02HKM.hdf MOD02QKM.hdf MOD021KM.hdf -of=crefl.1km.hdf
$HOME/NDVI/NDVI.src/crefl -f -v -500m \
    MOD02HKM.hdf MOD02QKM.hdf MOD021KM.hdf -of=crefl.hkm.hdf
$HOME/NDVI/NDVI.src/crefl -f -v -250m \
    MOD02HKM.hdf MOD02QKM.hdf MOD021KM.hdf -of=crefl.qkm.hdf
```

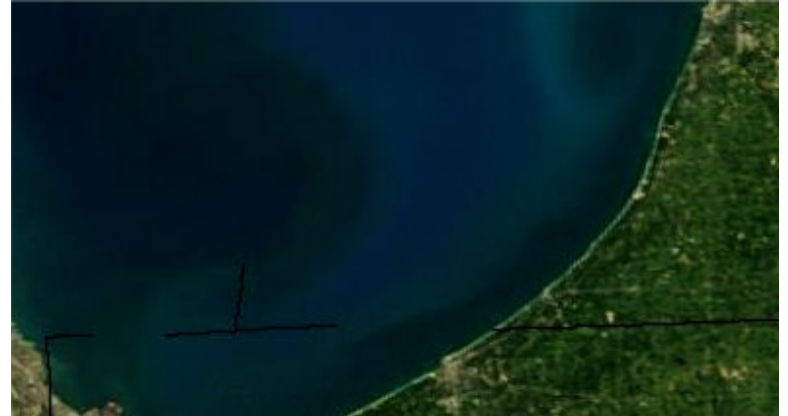
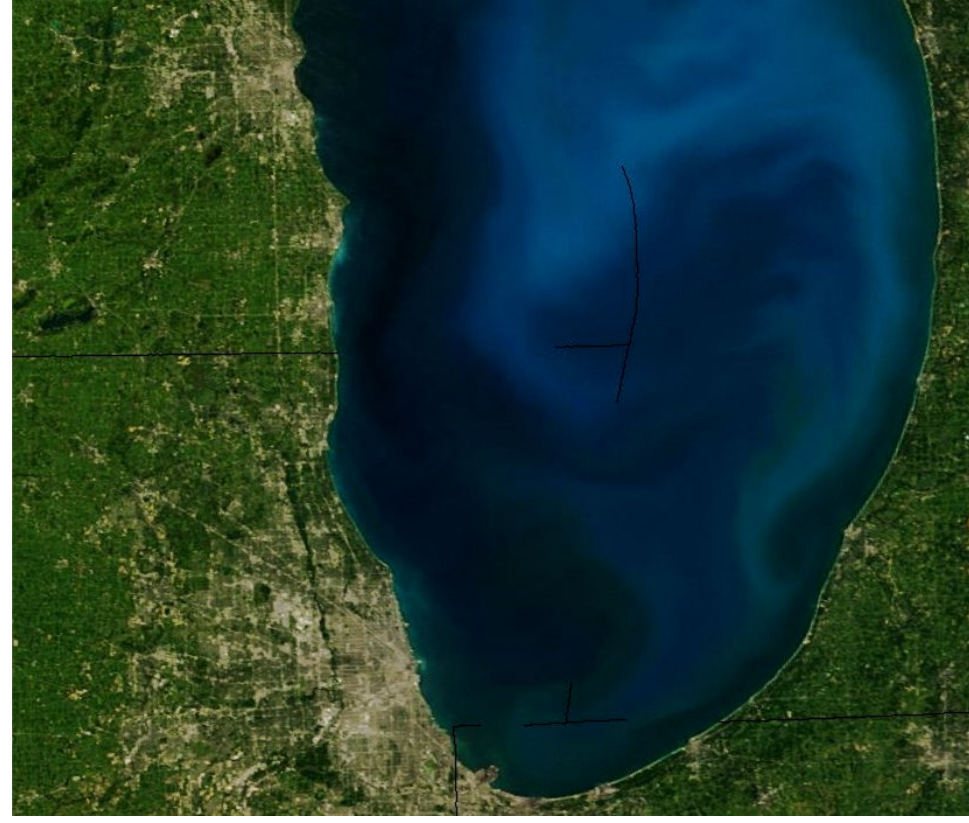


## MS2GT (MODIS Swath to Grid Toolkit)

- Developed at National Snow and Ice Data Center (NSIDC) by Terry Haran and Ken Knowles.
- Based on **mapx** library routines that have been well tested.
- Accounts for multiple lines per earth scan.
- Comes with Perl scripts that automate reprojection procedure.
- You can call low level routines directly (**ll2cr** and **fornav**).
- Calling low-level routines gives the greatest flexibility on input and output formats.
- Flexible text file format for defining output map projection and datum.
- Gives high quality results when supplied with high quality input.

Sensor Projection (250 m pixels)

Reprojected (250 m grid)



# MS2GT Input and Output Formats

When calling the low level routines **ll2cr** and **fornav**:

## *Input*

1. Image file (8, 16, 32-bit int or 32-bit float)
2. Corresponding latitude and longitude files (32-bit float)
3. Grid Parameter Definition file (ASCII text)

## *Output*

1. Reprojected image file (same type as input image file)
2. Optional latitude and longitude files for reprojected grid

Note: No dependence on details of MODIS L1B HDF format

# MS2GT Script Example

Step 1: Convert lat/lon to col/row

```
$ ll2cr -v -f 5416 100 40 \  
  lat_5416x4000.dat lon_5416x4000.dat AquaSA.gpd AquaSA
```

Step 2: Convert lat/lon to col/row

```
$ fornax 1 -v -t f4 5416 100 40 \  
  AquaSA_cols_05416_00100_00000_40.img \  
  AquaSA_rows_05416_00100_00000_40.img \  
  band02_5416x4000.dat 2550 3300 band02_proj_2550x3300.dat
```

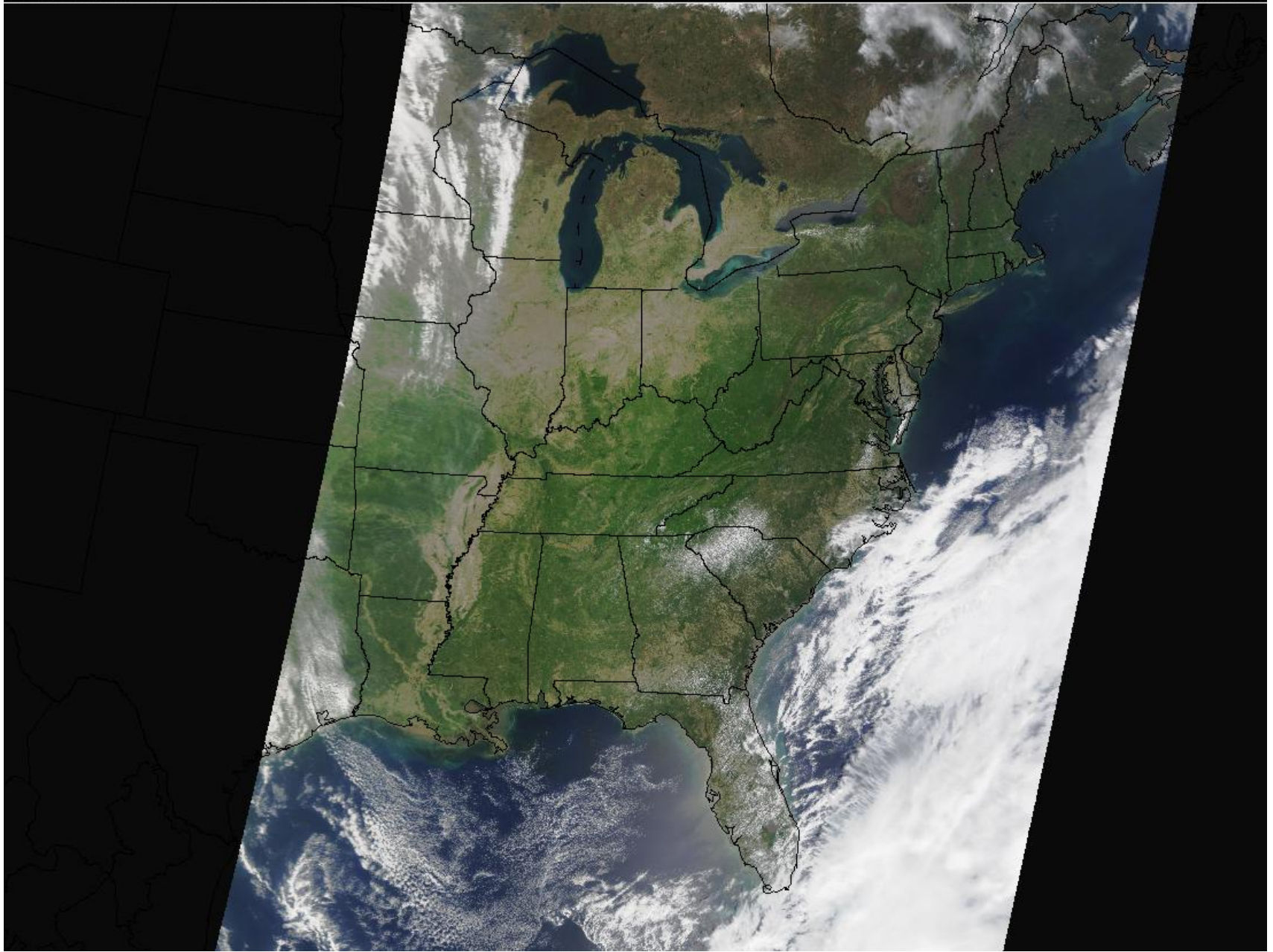
Default is weighted average of pixels mapped to each grid cell  
(nearest neighbor is optional).



# MS2GT used routinely for SSEC browse images

TERRA MODIS 2002-05-22 1616-1629 UTC Bands 010403: Eastern US

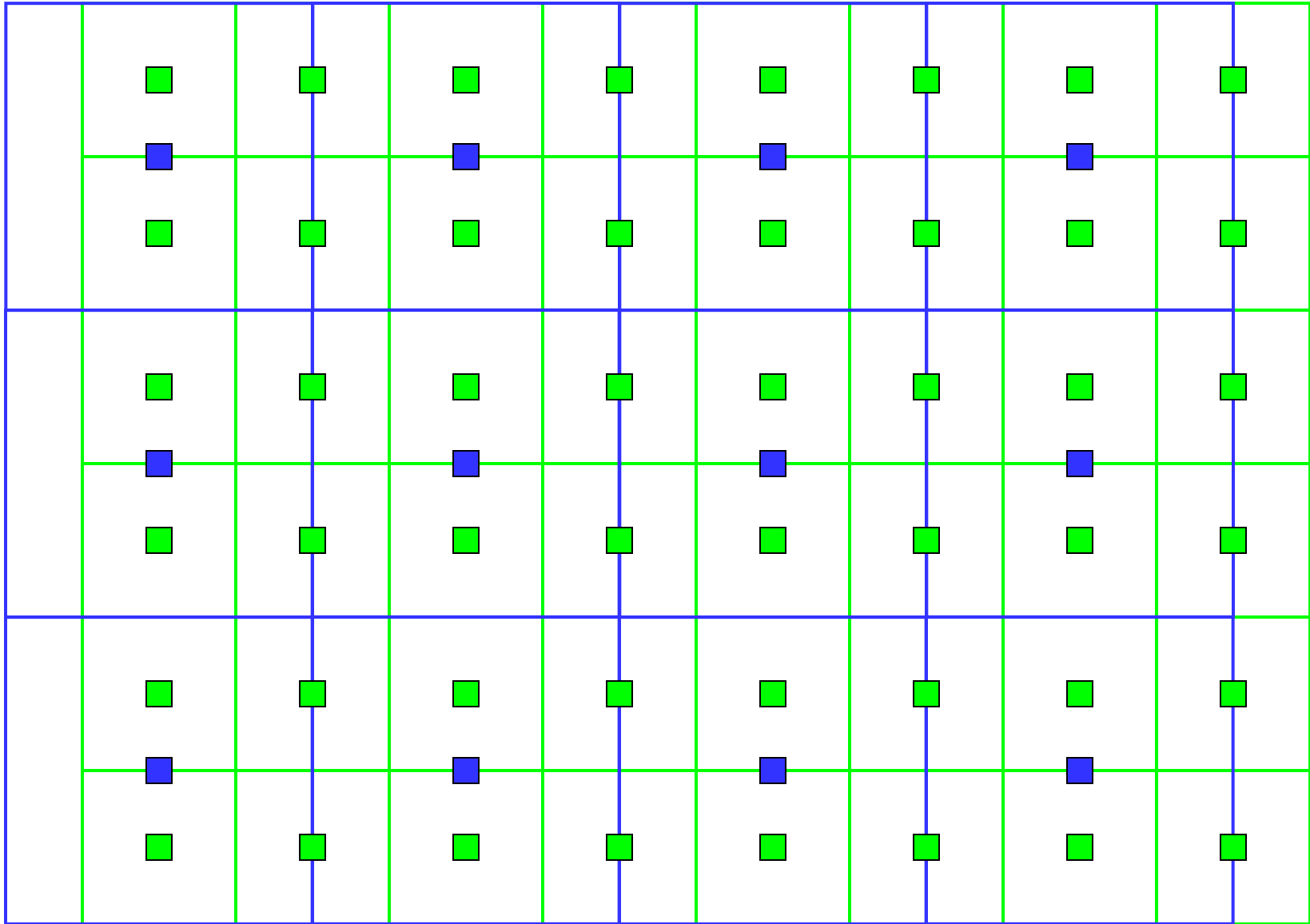
SSEC UW-MADISON DIRECT BROADCAST



# Geolocation Interpolation

Geolocation is defined at the nominal center of each 1000 meter pixel. To interpolate to 500 or 250 meter pixels:

1. Must handle each earth scan separately (do not process entire array with CONGRID or REBIN!).
2. Remember that centers of first 1000, 500, and 250 meter pixels across track are co-registered.
3. Can use bilinear interpolation for most (but not all) of the 500 or 250 meter pixels within each scan.
4. Must use linear extrapolation for the 500 and 250 meter pixels at the edge of each earth scan.



1000 meter pixels

500 meter pixels

# Image Interpolation

To interpolate 500 meter resolution image pixels to 250 meter resolution:

1. Must handle each earth scan separately (do not process entire array with CONGRID or REBIN!).
2. Remember that centers of first 1000, 500, and 250 meter pixels across track are co-registered.
3. Can use bilinear interpolation for most (but not all) of the 250 meter pixels within each scan.
4. Can use pixel replication for the 250 meter pixels at the edge of each earth scan.

# Resolution Sharpening

Use Band 1 to supply 250 meter resolution information for Bands 3 and 4, i.e.,

$$R = B_1^* / B_1$$

R is spatial resolution ratio

$B_1^*$  is band 1 @ 500 m interpolated to 250 m

$B_1$  is band 1 @ 250 m

Then

$$B_3 = B_3^* / R$$

$$B_4 = B_4^* / R$$

$B_3^*$ ,  $B_4^*$  are bands 3, 4 @ 500 m interpolated to 250 m

$B_3$ ,  $B_4$  are bands 3, 4 @ 250 m



# True Color Enhancement: First Cut

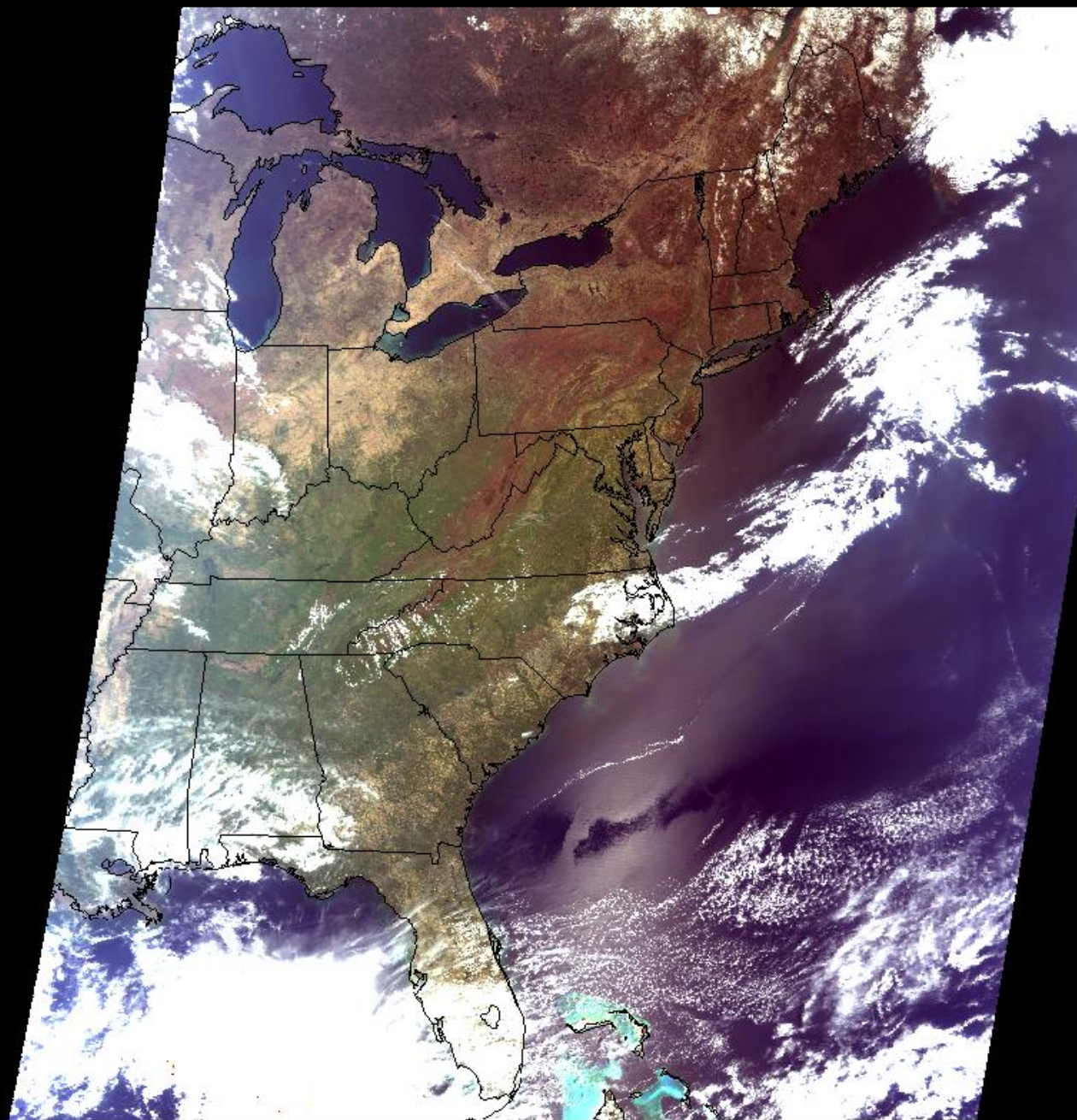
Linear enhancement of at-sensor reflectance.

Advantages:

- Easy to code

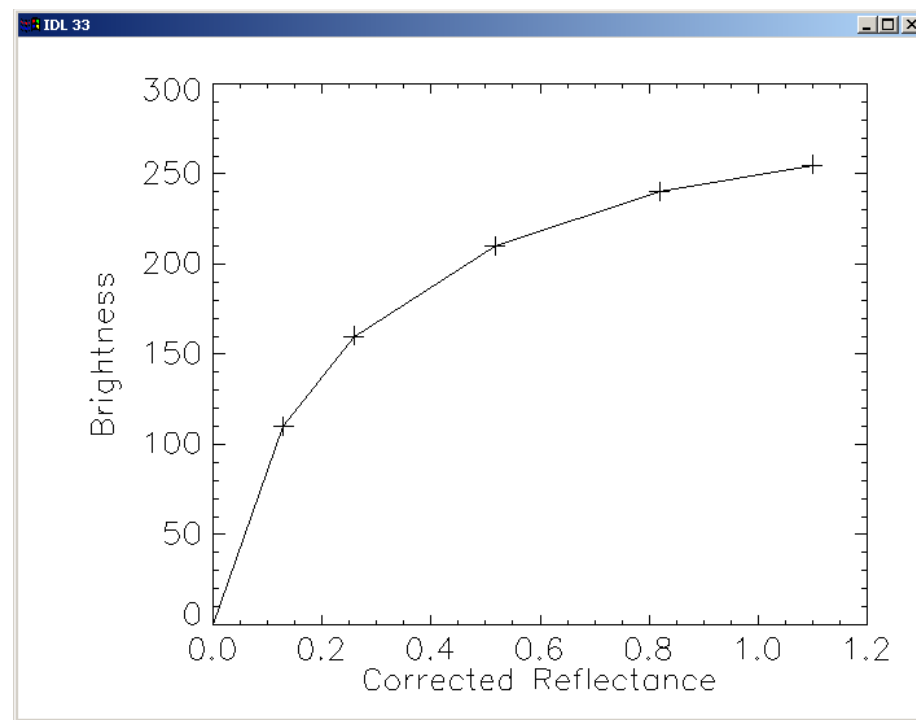
Disadvantages:

- Clouds are washed out
- Difficult to achieve balance between red, green, blue
- Bluish haze always appears at the image edges



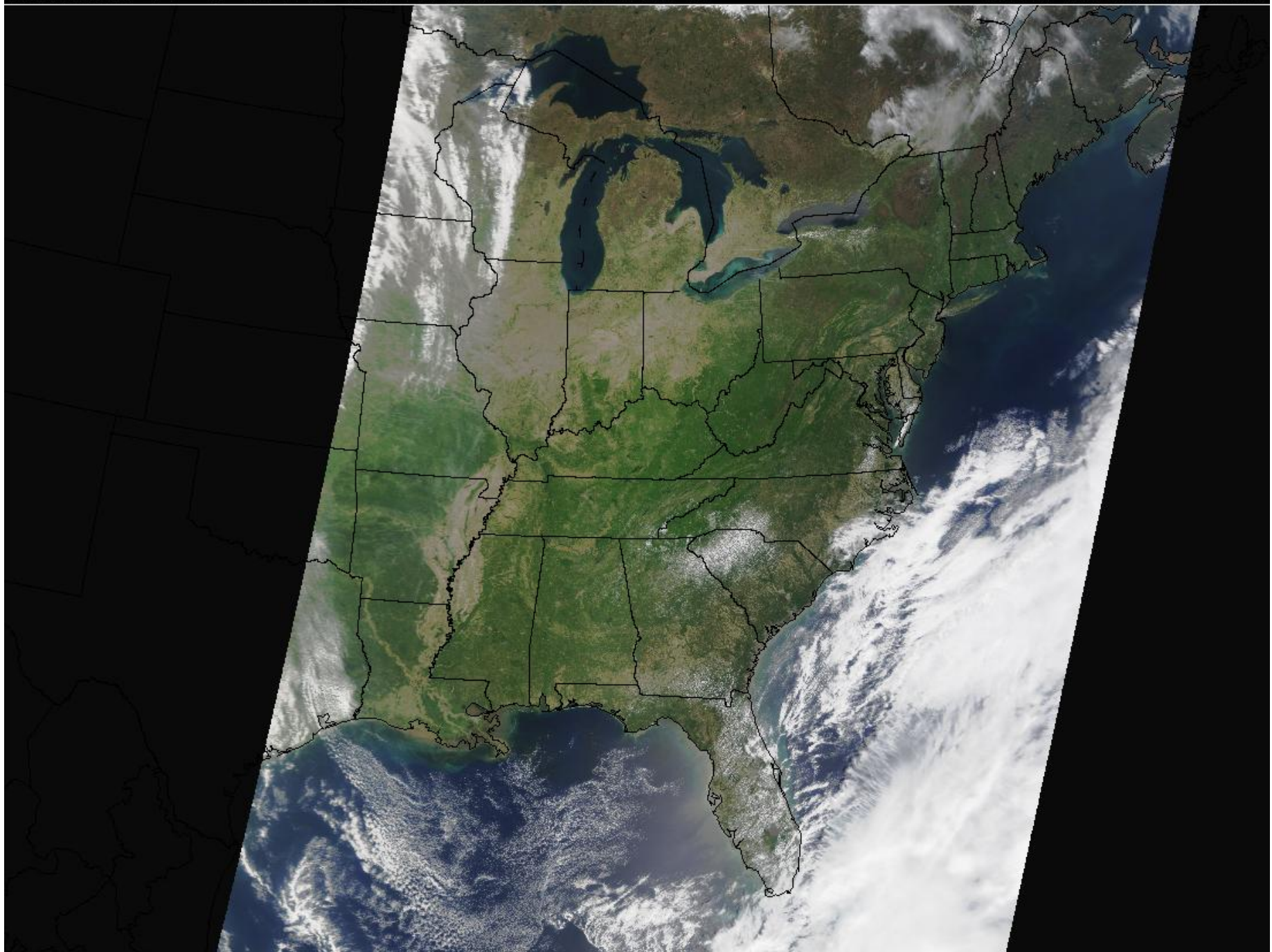
## Piecewise Linear Enhancement Curve

- Enhances low brightness regions (land, ocean), while de-emphasizing clouds.
- Same curve is applied to corrected reflectance in MODIS bands 1, 3, 4.



- Final step is to increase saturation by 25% and lightness by 5%





**What is the end result?**

Terra MODIS, Western Australia, 2002 day 196



Northwest Cape

Lake MacLeod



## **Where to Get the Tutorial**

Tutorial document (PDF), source code, sample data:

**<ftp://ftp.ssec.wisc.edu/pub/IMAPP/MODIS/TrueColor/>**