Landsat 8: Albedo[1]

The Alaska scene, which is dominated by snow, had by far the highest average albedo at 0.55. Both Florida and Mississippi scenes had similar average albedo value at around 0.16. The Dominica scene, which is dominated by water, had the lowest albedo value at 0.11.

Two methods of computing albedo were used: Liang's and Smith's.

Liang[2]:

$$\alpha^{\text{ETM+}} = 0.356\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 - 0.0018$$

Smith:

$$\alpha = \sum_{i=2-7} \frac{Refi \times Si \times \Delta\lambda i}{\Sigma Si \times \Delta\lambda i}$$

S= solar irradiance constant

$\Delta\lambda$ = band range

Since solar irradiance constants are not yet published by NASA for Landsat 8's new bands, I calculated them by calculating the Planck function with T=5778K and assuming Lambertian surface.

Formula: (Blackbody radiation from Planck function) * (Sun radius/distance between sun and Earth)^2 * π

Unfortunately, the results are more different from the published solar irradiance values for Landsat 7 than I had hoped.

Landsat 8 Band #	Landsat 8 Band Center Wavelength (µm)	Personal Landsat 8 Solar Irradiance Constants	NASA's Landsat 7 Solar Irradiance Constants	Landsat 7 Band Center Wavelength (µm)	Landsat 7 Band #
1	0.44	1719	-	-	-
2	0.48	1787	1969	0.45	1
3	0.56	1746	1840	0.56	2
4	0.655	1536	1551	0.66	3
5	0.865	997	1044	0.835	4
6	1.61	811	225	1.65	5
7	2.20	75	82	2.22	7
8	0.59	1691	1368	0.71	8

Note: Landsat 8's Band 6 disagree with the its equivalent band in Landsat 7 the most.

[1] For all of the albedo calculations, I used TOA reflectance values that accounted for the solar angle.

[2] Liang, S. (2000). "Narrowband to broadband conversions of land surface albedo I algorithms." Remote Sensing of Environment. 76: 213-238.

While Liang specified the input to his formula be surface spectral reflectance values, I used instead the TOA reflectance values for both methods. Though albedo range is 0.0 to 1.0, both methods of calculating albedo resulted in greater than 1 values in all of the scenes.

	Method	Min	Max	Mean	St Dev
Alaska	Liang	0.037550	1.330256	0.559939	0.218388
	Smith	0.062502	1.238902	0.534064	0.202683
Dominica	Liang	0.019593	1.172171	0.107577	0.098908
	Smith	0.041085	1.145529	0.122222	0.089566
Florida	Liang	0.015293	1.193961	0.162354	0.120683
	Smith	0.038433	1.178105	0.158633	0.110411
Mississippi	Liang	0.030021	1.084479	0.155666	0.057196
	Smith	0.052452	1.068955	0.129215	0.043890

Comparison of Liang and Smith Methods

Band Math: **B1-B2 = Liang – Smith**

Overall, the Liang's method yielded albedo values that were slightly higher than the Smith's method, except for the Dominica scene.

Difference in Albedo = B1-B2 = Liang's - Smith's

	Min	Max	Mean	St Dev
Alaska	-0.113785	0.108876	0.025875	0.019283
Dominica	-0.075537	0.166306	-0.014645	0.016157
Florida	-0.098450	0.158823	0.003720	0.025338
Mississippi	-0.066396	0.133971	0.026451	0.030297

Note: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

Checking the Validity of Albedo Values

Given the seemingly inaccurate solar irradiance constants calculated for Smith's method, are the albedo values reasonable?

Yes, since both Liang and Smith albedo values are similar. However, they will remain a source of error. The following analysis shows how albedo changes with respect to temperature – a characteristic pattern for different land cover.

- ***Alaska***

Depending on which the surface is receiving more or less sunlight,

Snow/Ice: 0.7 - >1 (Liang's higher than Smith's by .05)

Bare Soil: 0.25

River: 0.6 at 273K

- ***Dominica***

Water: < 0.10, (L-0.046 R-0.067) at 295K

Vegetation: 0.1 - 0.2 at 295K

Bare Soil: 0.2-0.25 at 290K

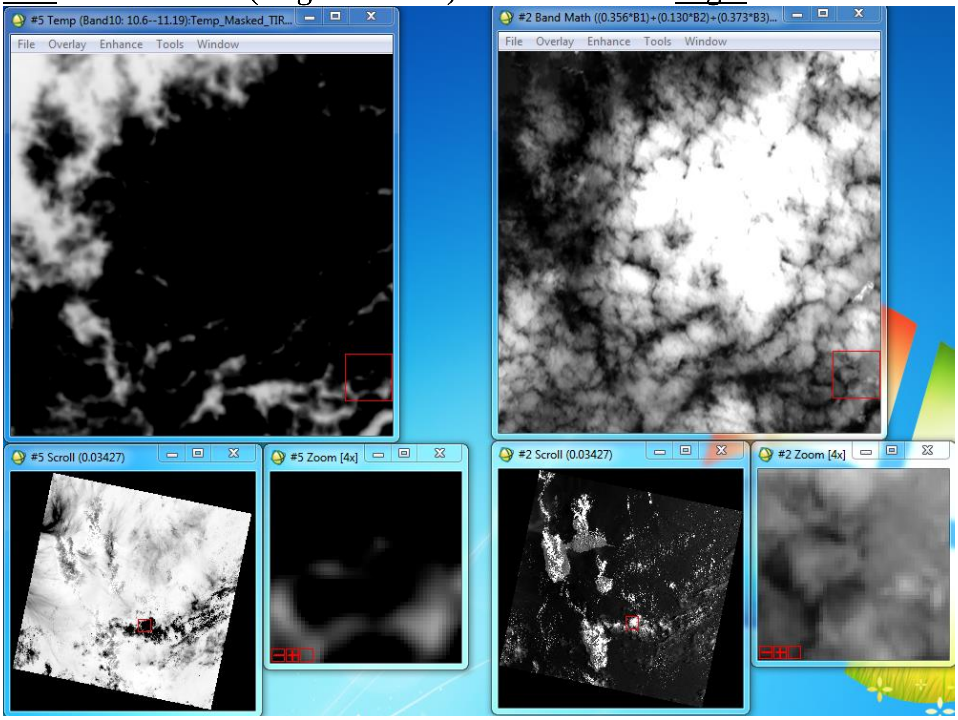
Urban: 0.15-0.25 at 300K

Clouds: 0.6 – 1.0 (285K), 0.6 for 263K, higher for 286K

Cyan Pixels: 0.3-0.6 at 285K

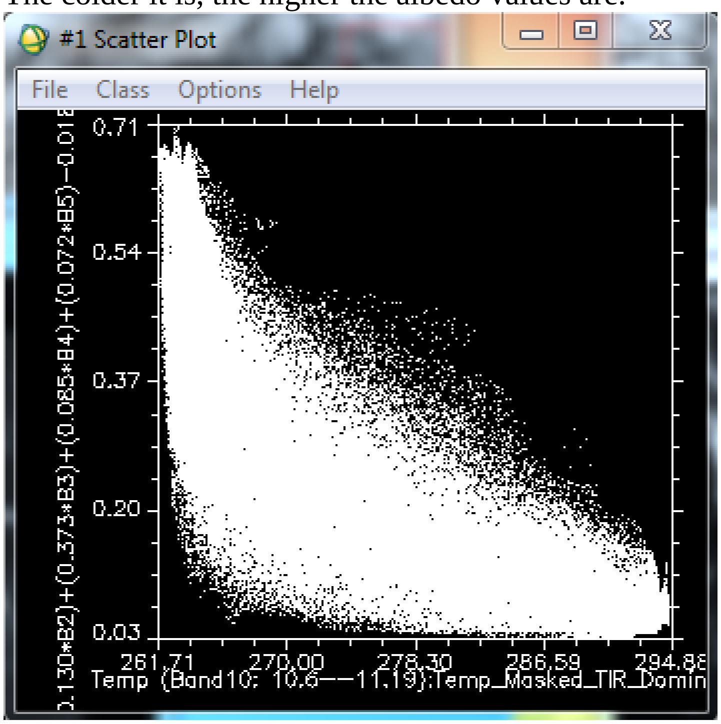
- Cumulous clouds (high albedo, low temp) over water

Left: TIR Band 10 (Degree Kelvin) Right: Albedo



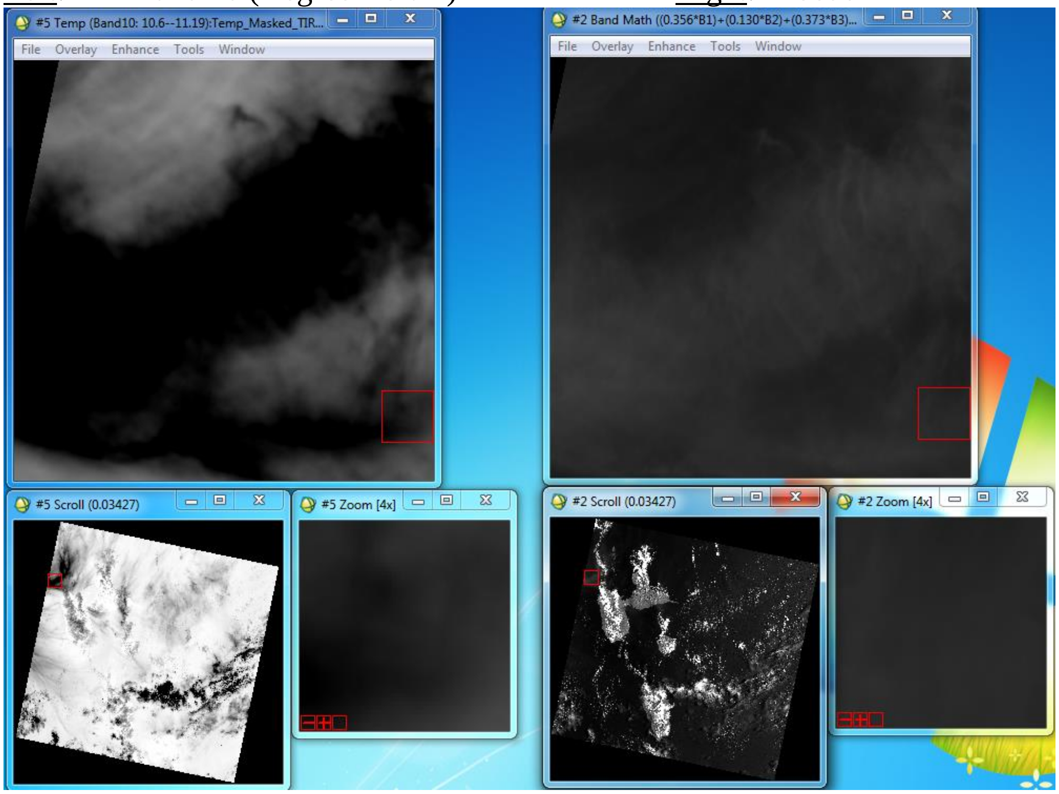
Scatter plot of the image window shown above. X-axis is Temperature in Degree Kelvin, and Y-axis is Albedo.

The colder it is, the higher the albedo values are.

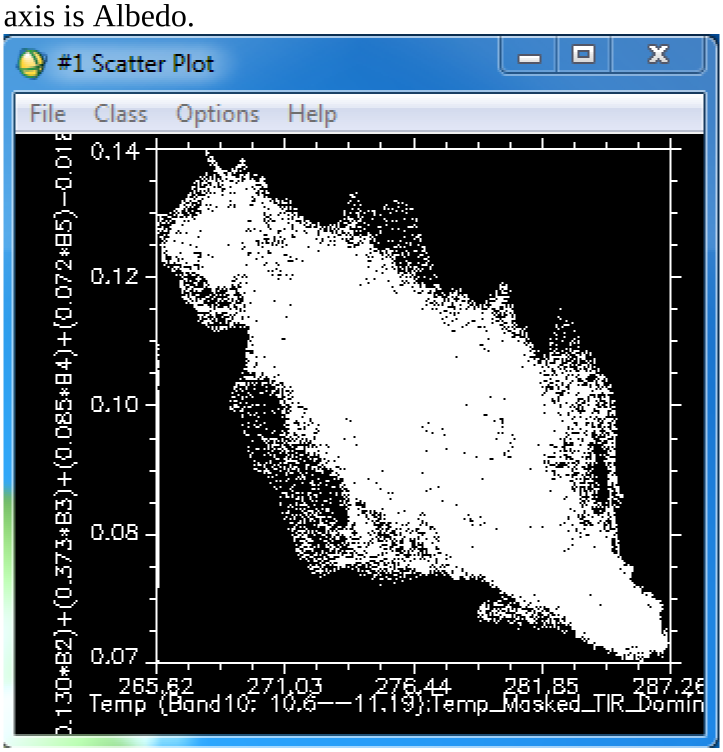


- Definitely for cirrus clouds (low albedo, low temp)

<u>Left</u>: TIR Band 10 (Degree Kelvin) <u>Right</u>: Albedo

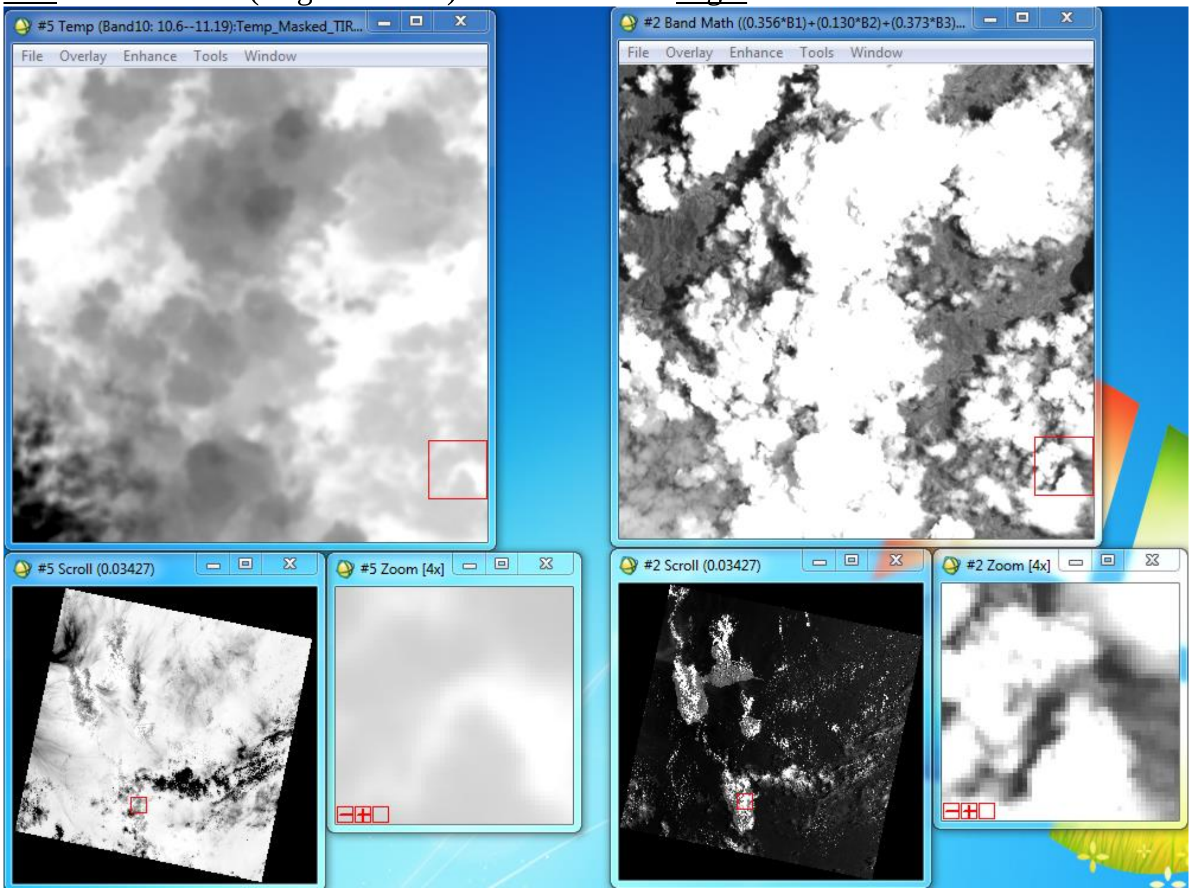


Scatter plot of the image window shown above. X-axis is Temperature in Degree Kelvin, and Y-axis is Albedo.

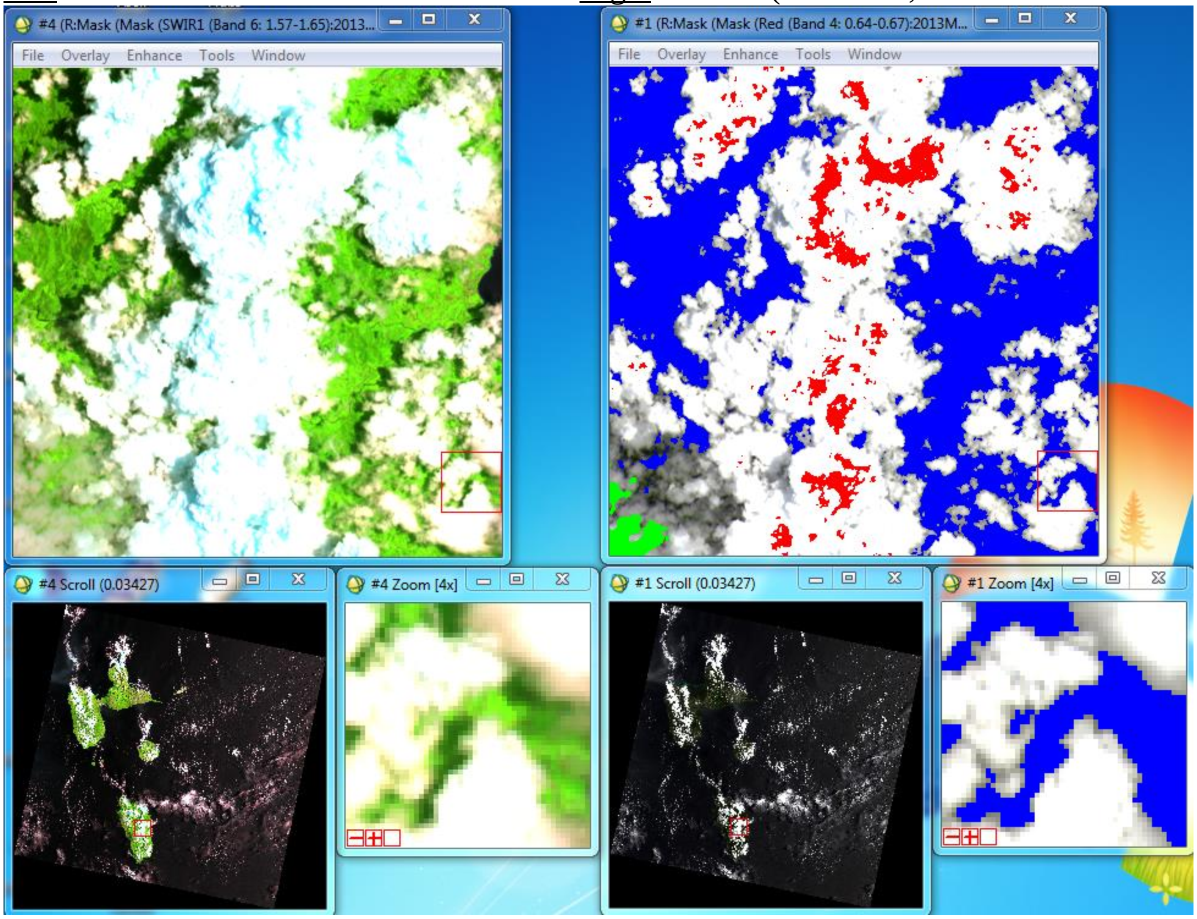


- Clouds (high albedo, low to moderate temp) over vegetation

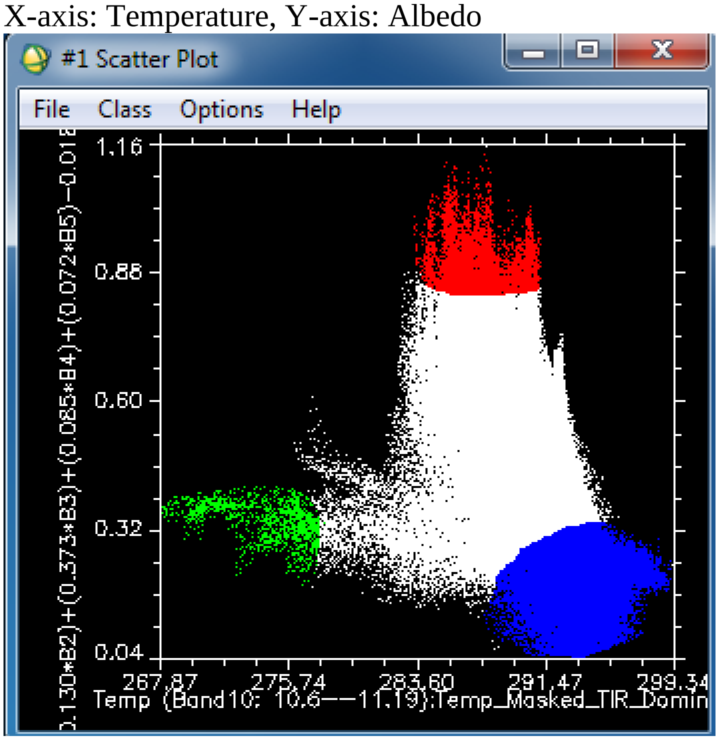
Left: TIR Band 10 (Degree Kelvin) Right: Albedo



Left: 654 - RGB Right: Albedo (Classified, see Scatter Plot below)



X-axis: Temperature, Y-axis: Albedo



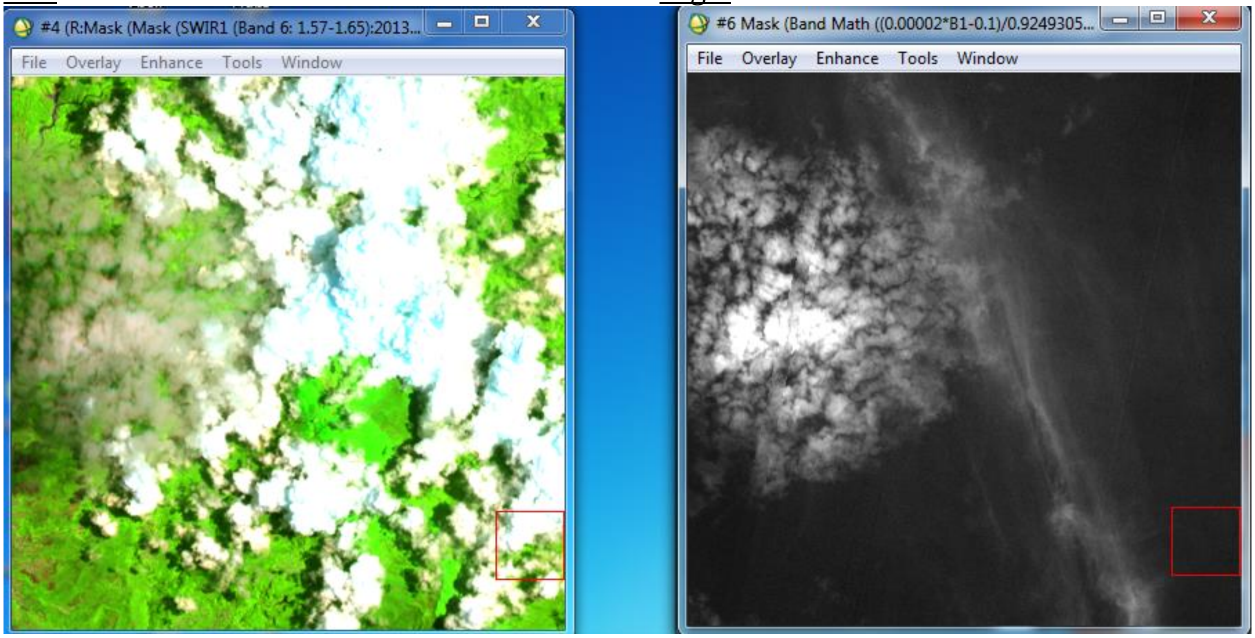
Class Blue: Vegetation

Class Green: Cirrus Clouds? (See next page)

Class Red: Cumulous clouds with high albedo. Note that these high albedo pixels do not necessarily align with cyan pixels, similarly to high reflectivity pixels.

In order to better understand the clouds classified as green, the following images are of the area that is more west of the area show in the previous page. The green class seems to be a part of the tannish clouds (~270K) in the west.

Left: 654 – RGB Right: Cirrus Band



- ***Florida***

Water: ~0.1 (L-0.09, S-1.1) at 297K

Vegetation: 0.05-1.5 at 300K

Bare Soil: 0.12-15 at 303K

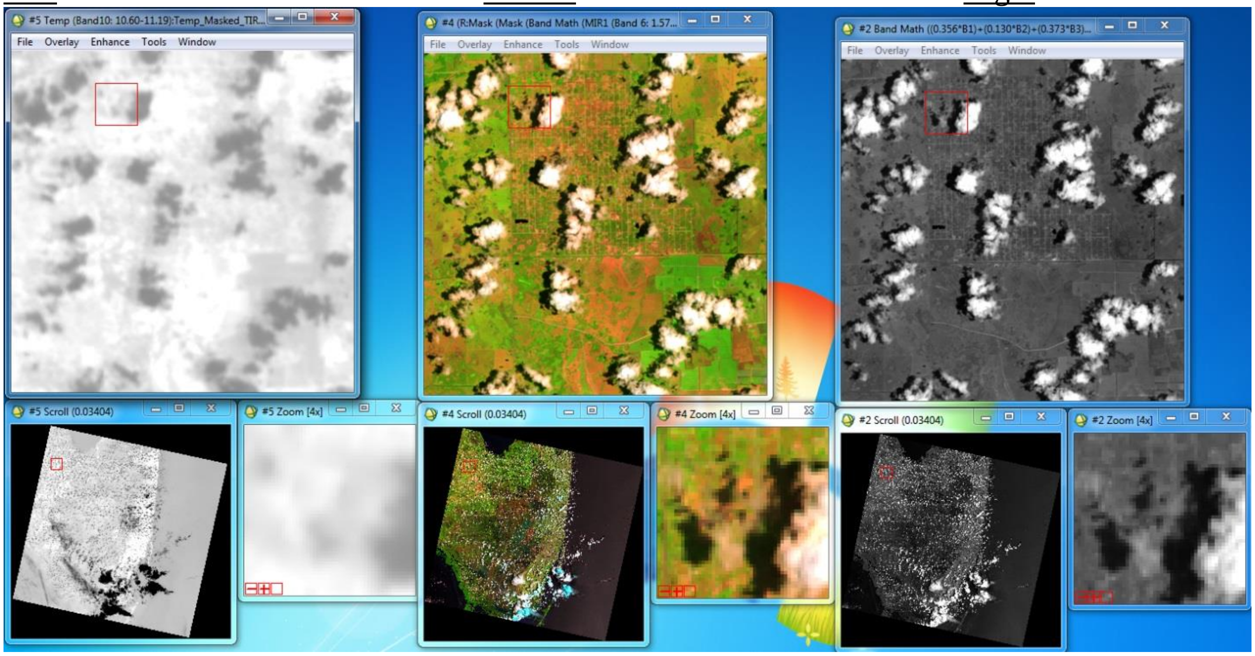
Agricultural Fields: ~0.2 (L-0.21, S-0.19) at 304K

Urban: 0.2-0.5 at 307K

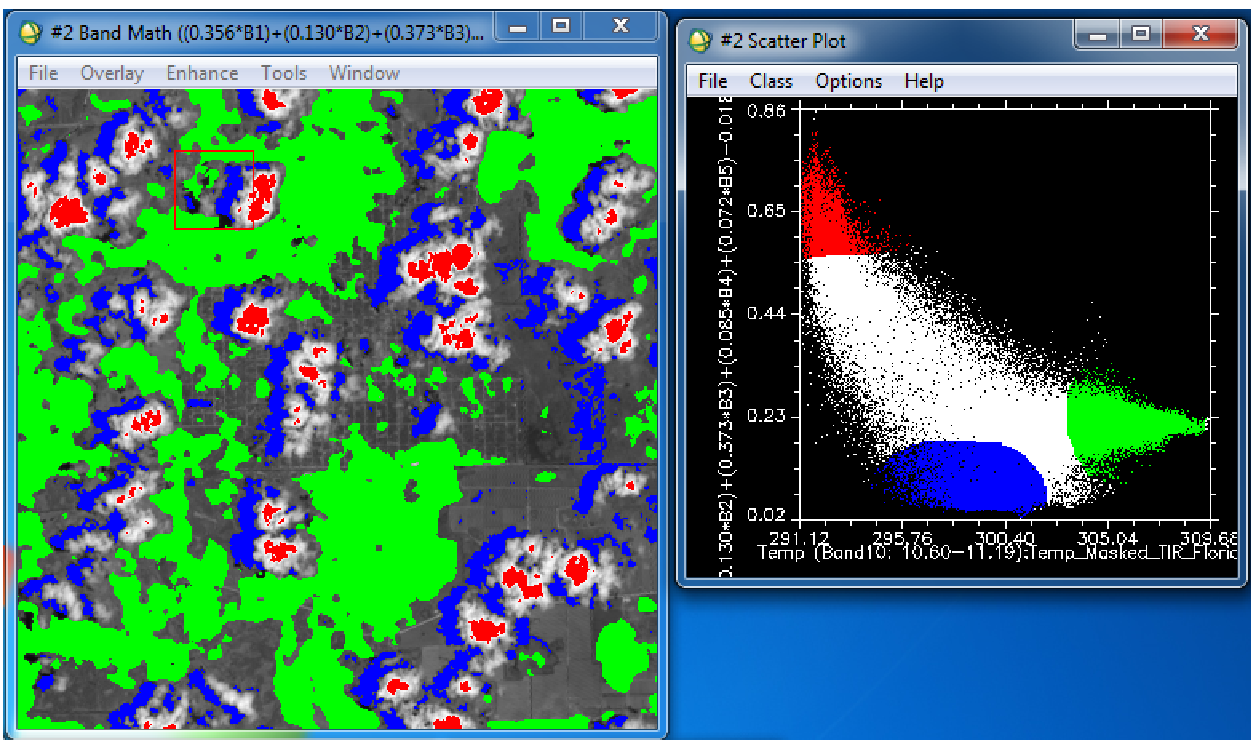
Clouds:

- Small cumulous clouds (Moderate Temp, Moderate Albedo)

Left: TIR Band 10 Middle: 654 – RGB Right: Albedo



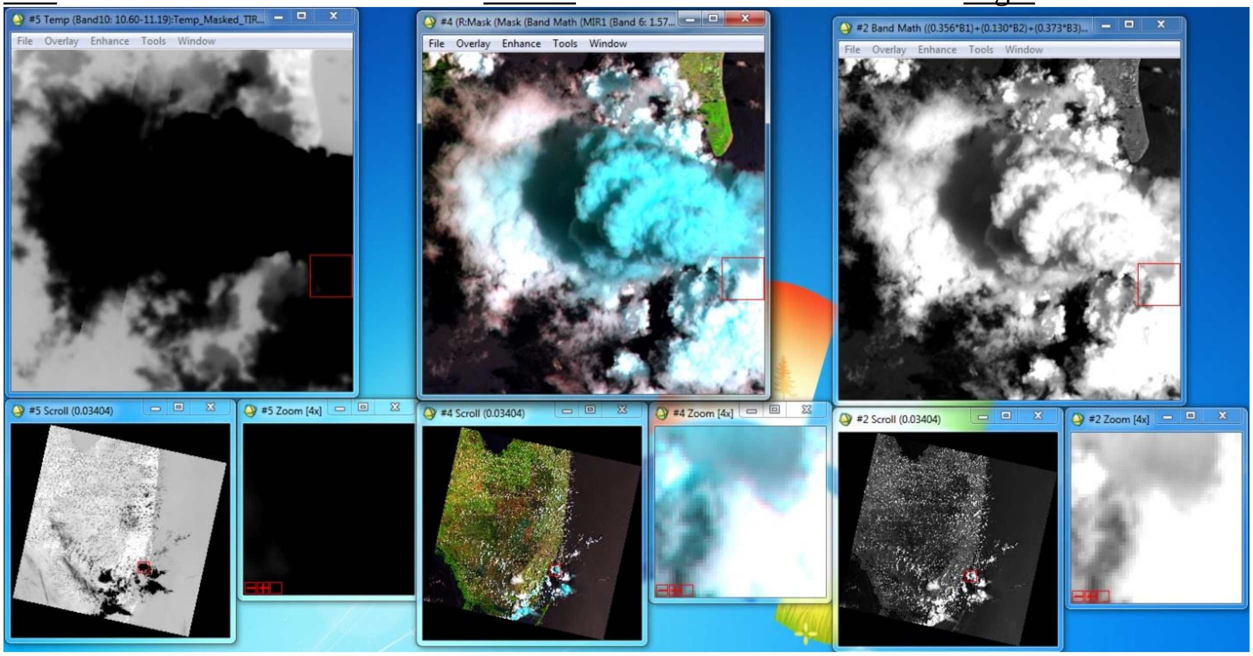
Below is the same image above: Scatter Diagram – X-Axis: Temperature, Y-Axis: Albedo



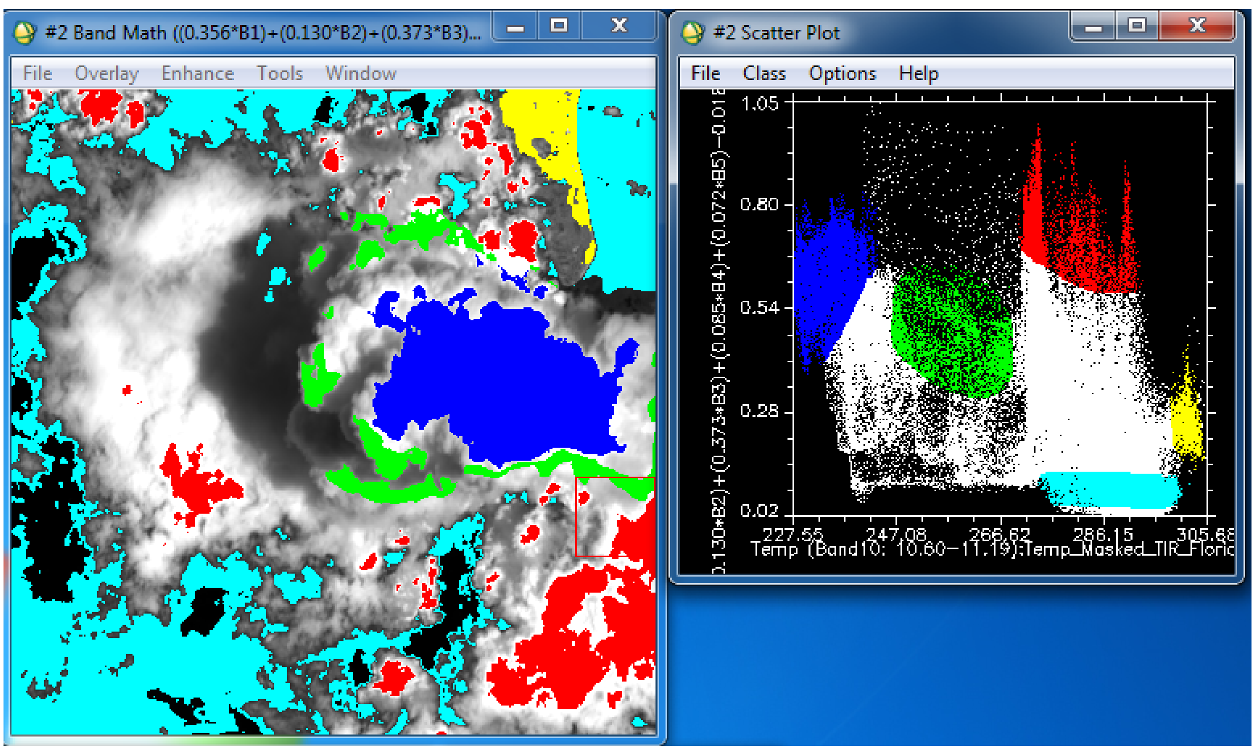
Classes: Red – Clouds Green - Bare Soil/Vegetation Blue - Cloud Shadows/Vegetation

- Thunderstorm Clouds

<u>Left</u>: TIR Band 10 <u>Middle</u>: 654 – RGB <u>Right</u>: Albedo



Below is the same image above: Scatter Diagram – X-Axis: Temperature, Y-Axis: Albedo



<u>Classes</u>: Red – Warmer Cumulous Clouds Green – Clouds at the junction of ice and liquid

Blue – Anvil (Ice) Yellow – Land (Urban) Light Blue – Water

❖ ***Mississippi***

<u>Water</u>: <0.1 at 293K

<u>Vegetation</u>: ~0.17 at 290K

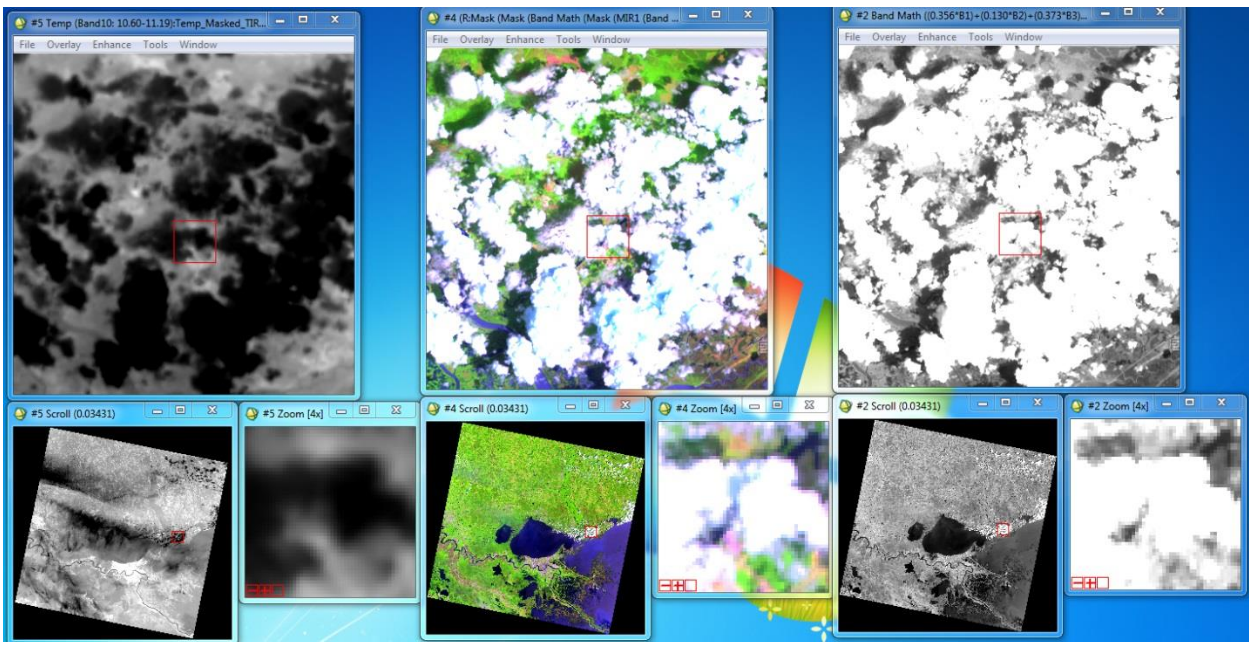
<u>Bare Soil</u>: ~0.15 at 296K

<u>Urban</u>: ~0.20 at 305K

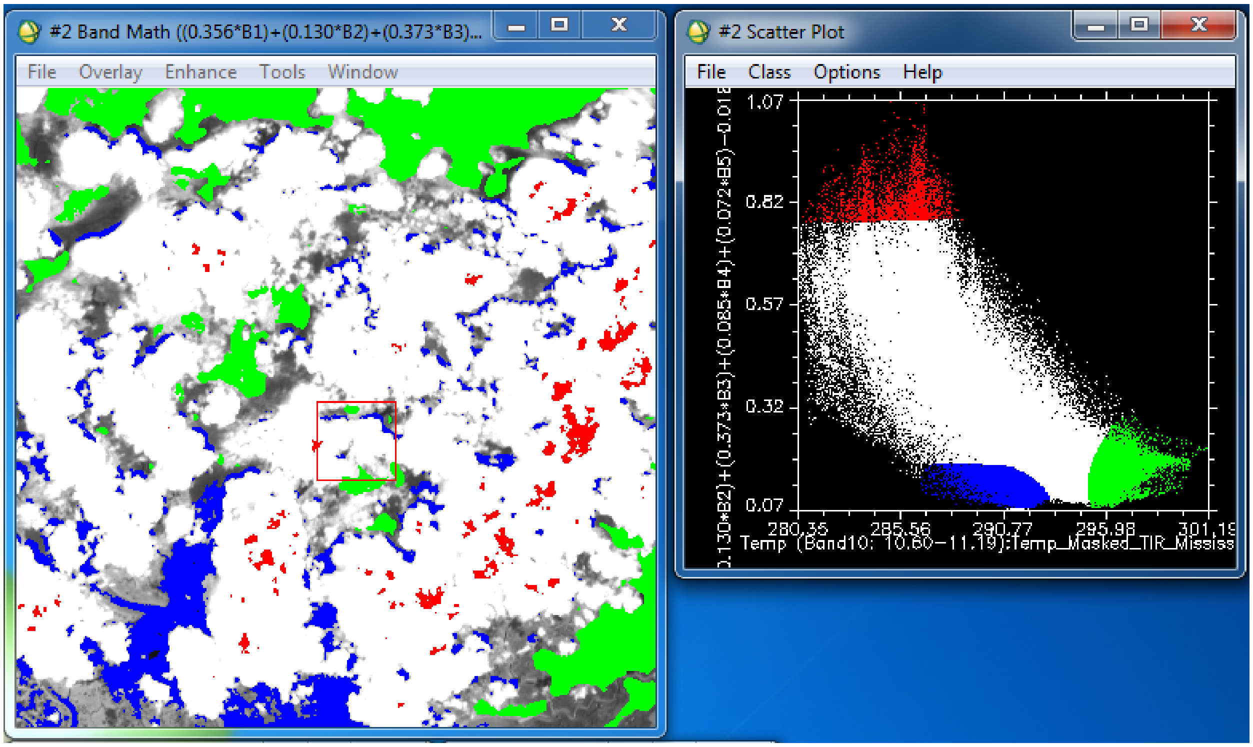
<u>Clouds</u>:

- Small Cumulous Clouds over Land

<u>Left</u>: TIR Band 10 <u>Middle</u>: 654 – RGB <u>Right</u>: Albedo



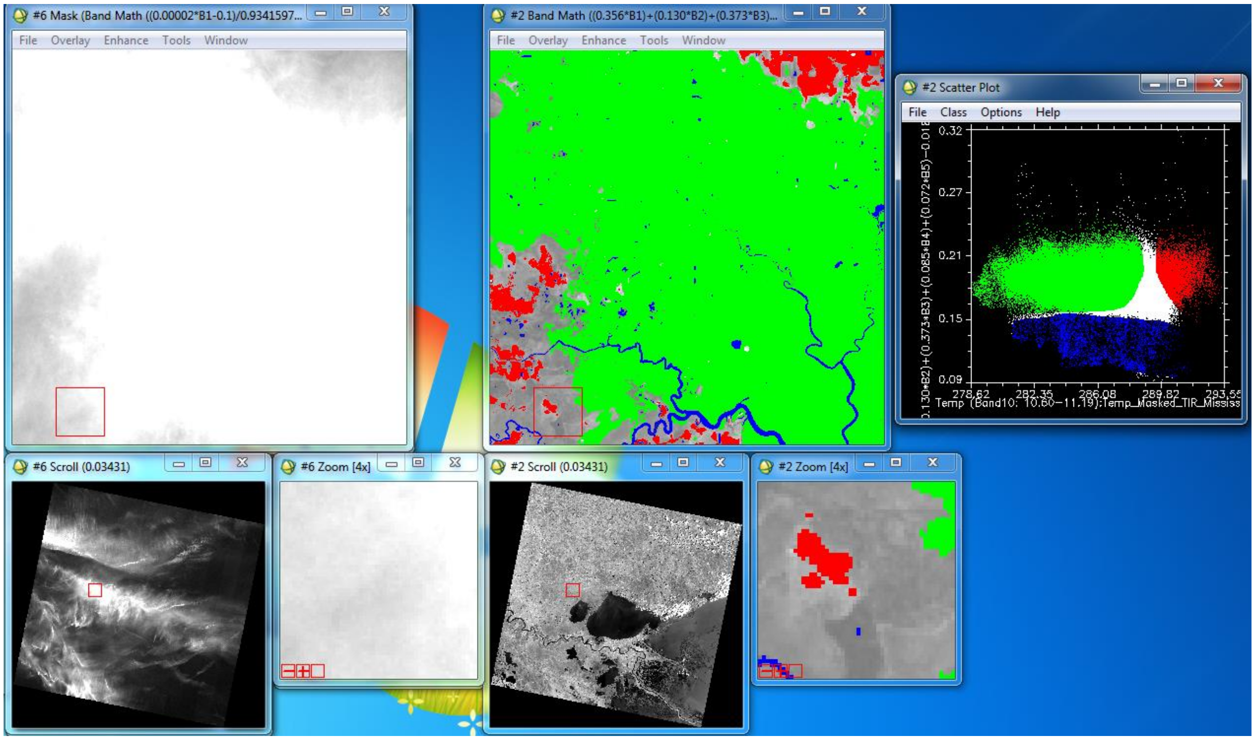
Below is the same image above: Scatter Diagram – X-Axis: Temperature, Y-Axis: Albedo



Classes: Red – Warmer Cumulous Clouds   Green – Vegetation   Blue – Cloud Shadows

- Cirrus Clouds over Land

<u>Left</u>: Cirrus Band <u>Middle</u>: Classified Image <u>Right</u>: Scatter Plot
X-Axis: Temperature,
Y-Axis: Albedo



<u>Classes</u>: Red – Vegetation Green – Cirrus Cloud Blue – Water

Comparing Liang's and Smith's Methods over Different Land Cover

Unless otherwise noted, the images below are from the file where I subtracted Smith's albedo values from Liang's: DATE_Ref_Albedo_Difference

The 2-D scatter plots - X-axis: Liang's albedo values, Y-axis: Smith's albedo values. Both X and Y axes' ranges are the same for easier comparison.

❖ ***Alaska:*** 2013April22_Ref_Albedo_Difference

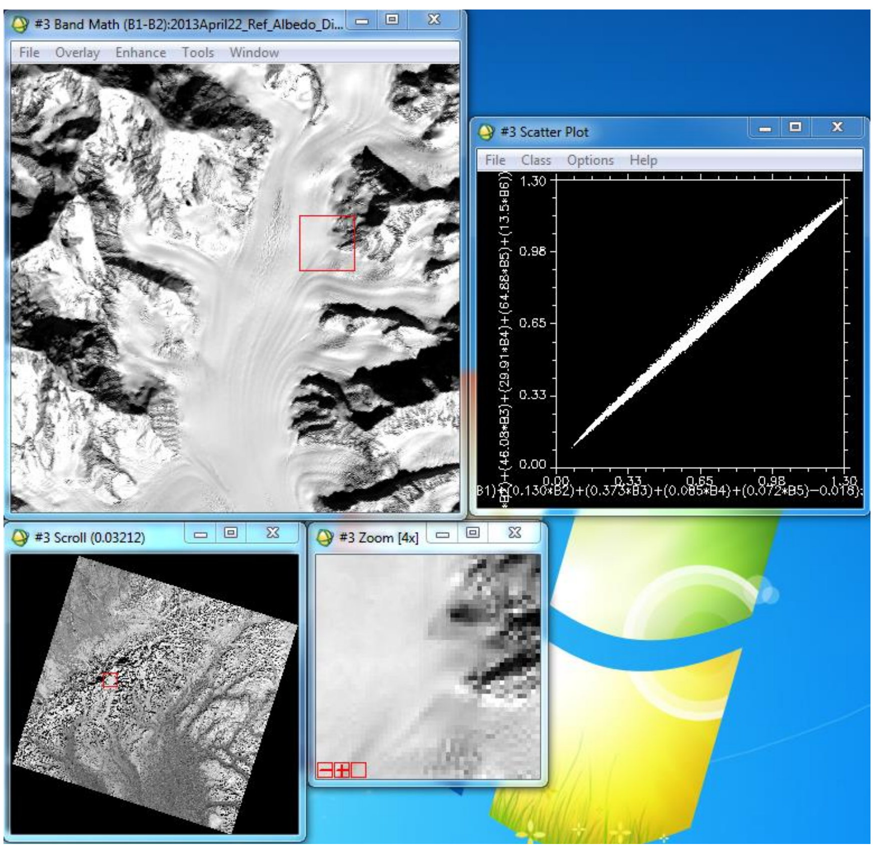
Summary: B1-B2 = Liang's - Smith's.

	Min	Max	Mean	St Dev
Alaska	-0.113785	0.108876	0.025875	0.019283
Dominica	-0.075537	0.166306	-0.014645	0.016157
Florida	-0.098450	0.158823	0.003720	0.025338
Mississippi	-0.066396	0.133971	0.026451	0.030297

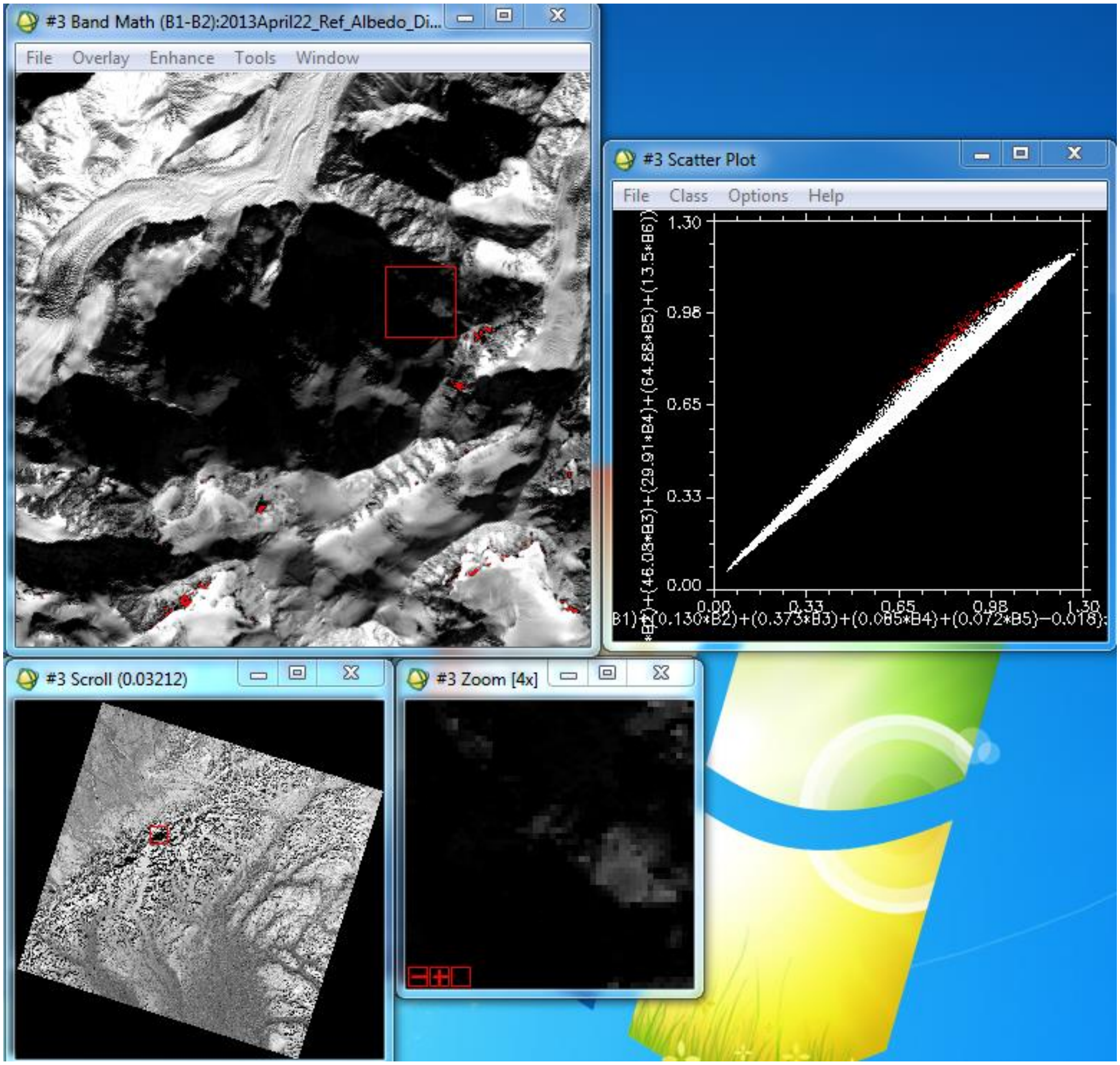
Note: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

The albedo values for both methods are similar across different landcover. Over snow/ice that is in the sun, Liang's albedo values are bigger by 0.05. Otherwise, Smith's are bigger in the shadows by 0.02 and in the melting ice by 0.06.

- Snow/Ice in Sunlight (Albedo Difference = 0.05)

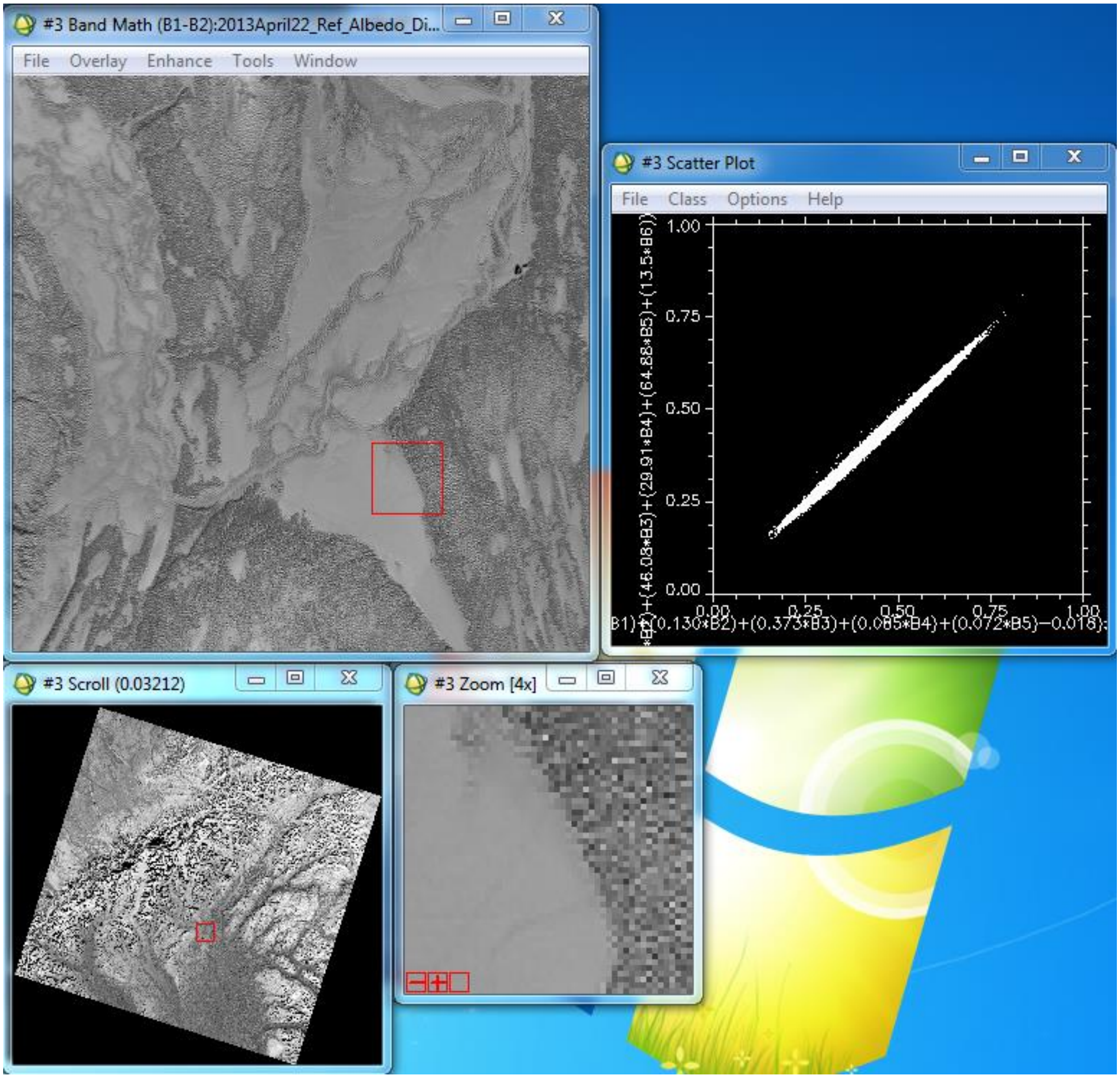


- Snow/Ice in Shadow (-0.02)

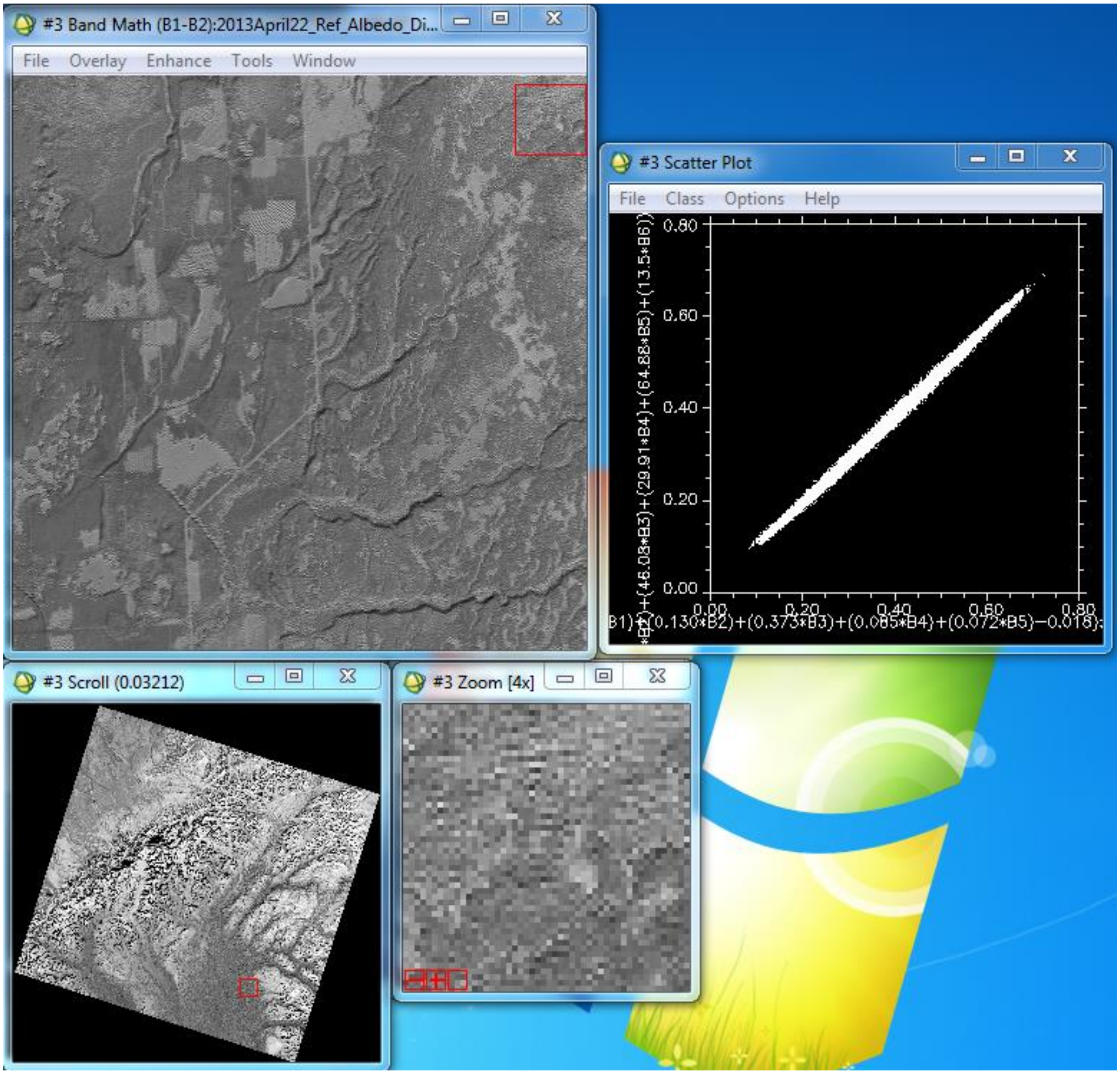


Note: The red highlighted pixels are those in the shadows, and Smith's values are bigger by 0.06.

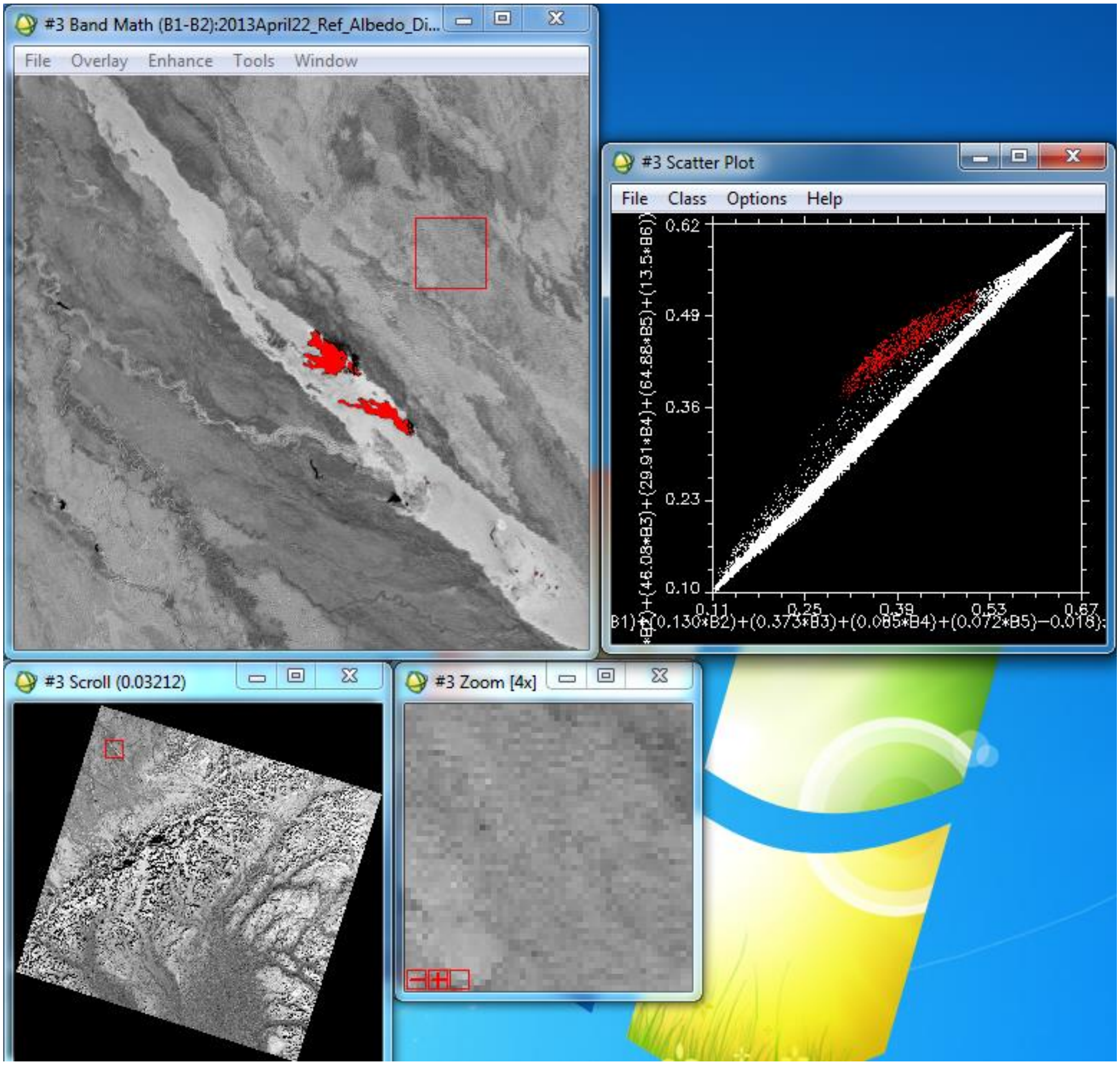
- Icy Water (0.025)



- Bare Soil (0.01)



- Melting Ice on the River (-0.06)



<u>Note</u>: The red highlighted pixels are those of melting ice on the river. These pixels indicate Smith's values are ~0.08 bigger.

❖ ***Dominica***: 2013May05_Ref_Albedo_Difference.

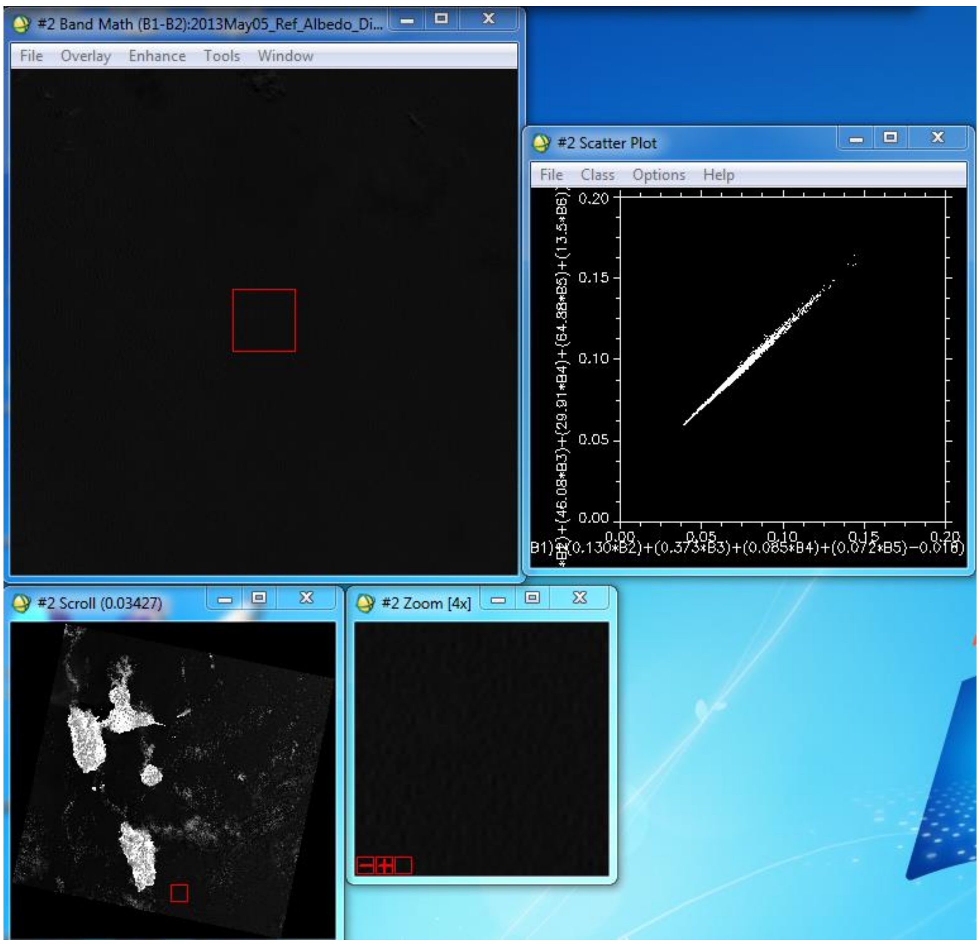
Again, the albedo values are similar for both methods. In water, the Smith's albedo values are bigger by 0.02. On the other hand, the Liang's values are bigger for clouds by 0.01 and for vegetation by 0.07, for soil by 0.02, and for urban by 0.01.

<u>Summary</u>: B1-B2 = Liang's - Smith's

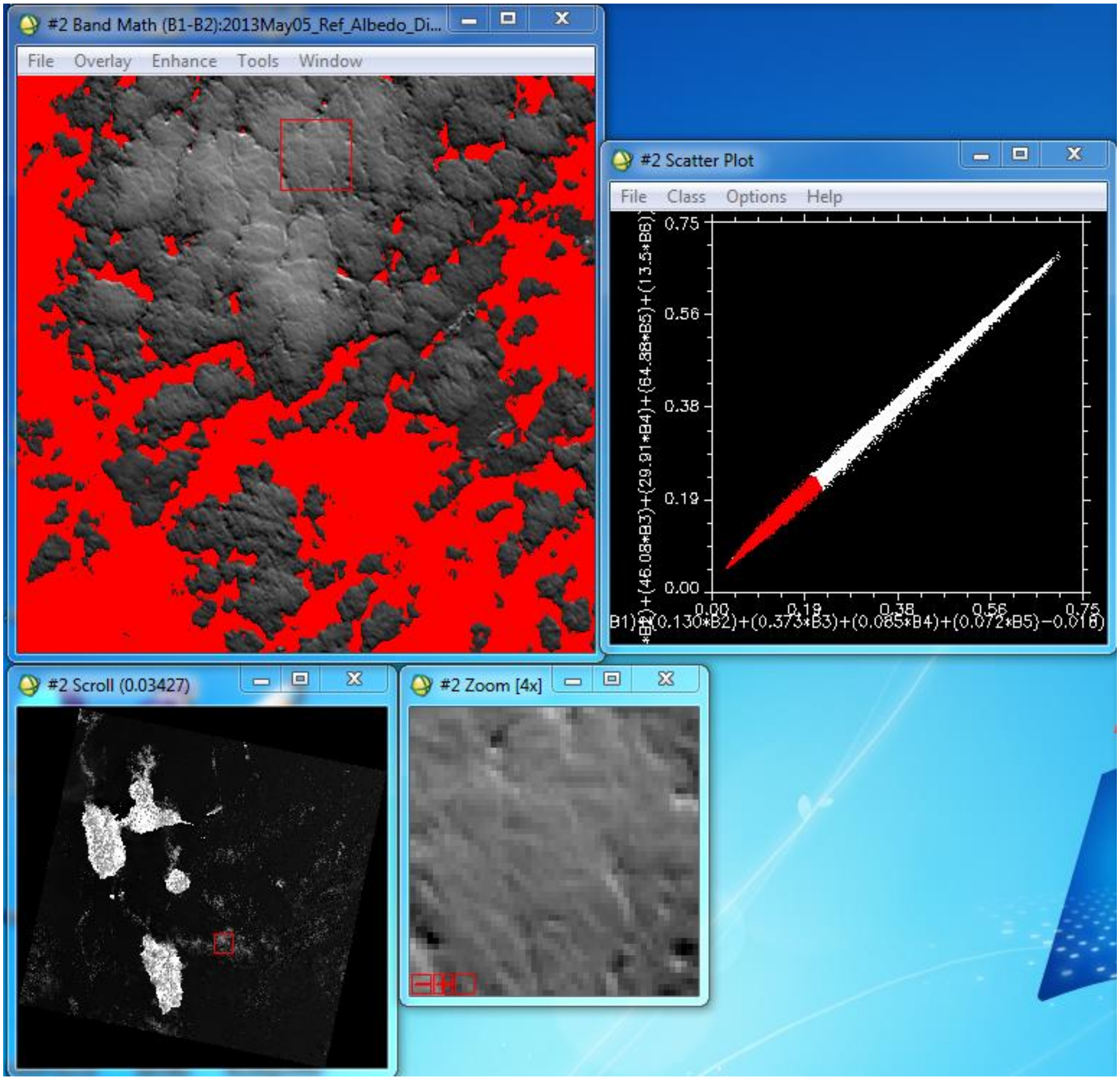
	Min	Max	Mean	St Dev
Alaska	-0.113785	0.108876	0.025875	0.019283
Dominica	-0.075537	0.166306	-0.014645	0.016157
Florida	-0.098450	0.158823	0.003720	0.025338
Mississippi	-0.066396	0.133971	0.026451	0.030297

<u>Note</u>: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

- Water (Albedo Difference = -0.02)



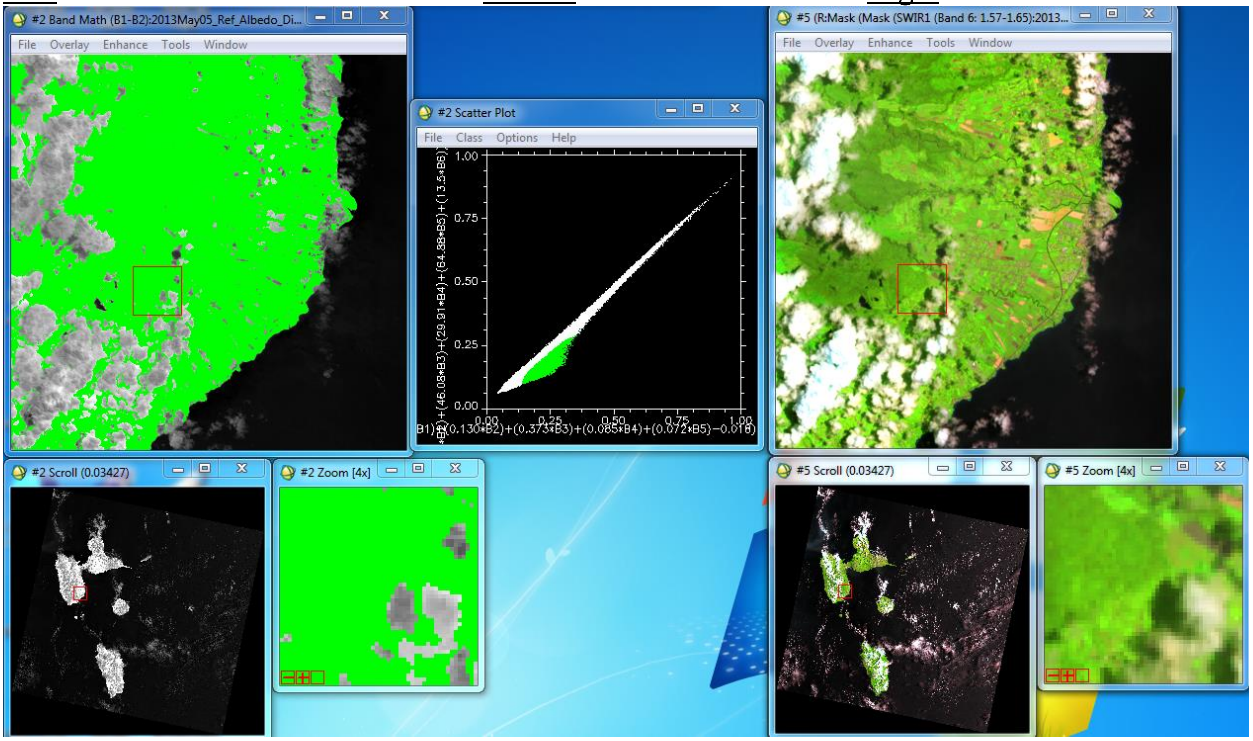
- Clouds over Water (0.01)



Note: Red pixels indicate Water

- Vegetation (0.07)

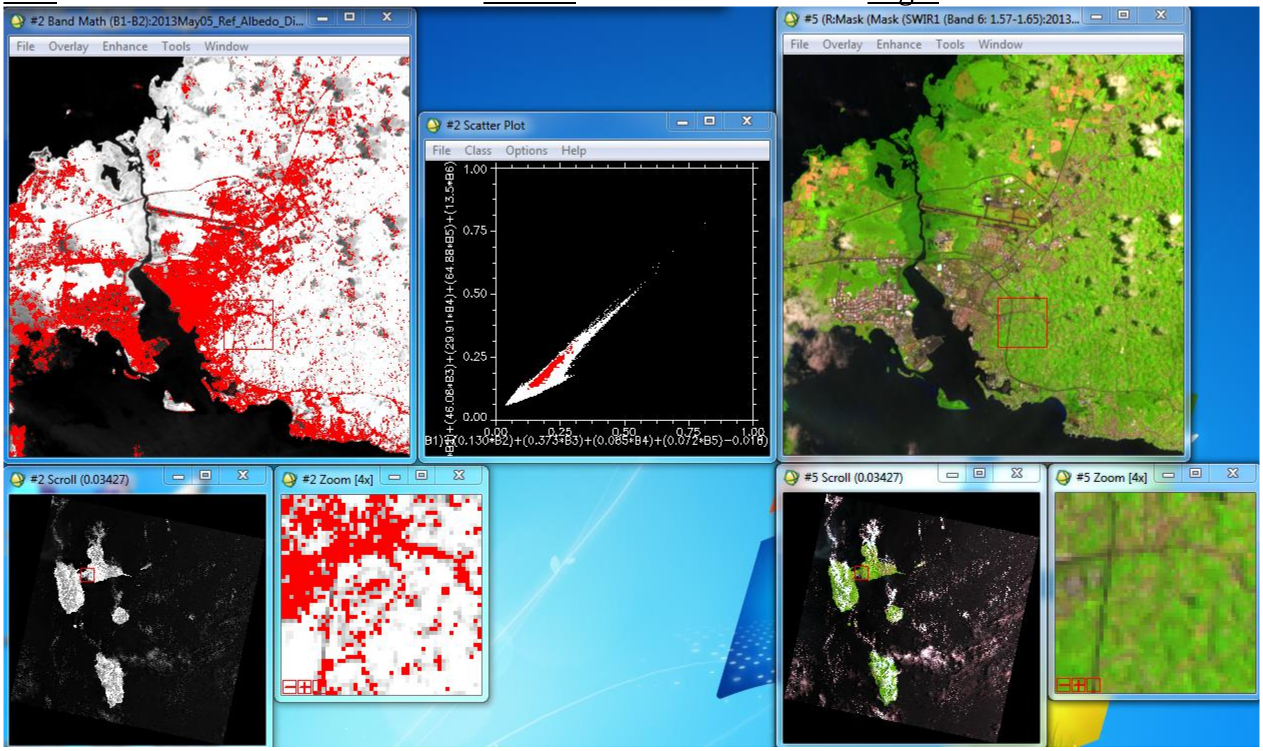
<u>Left</u>: Albedo Difference <u>Middle</u>: Scatter Plot <u>Right</u>: 654 - RGB



<u>Note</u>: Green pixels indicate vegetation.

- Urban Area (0.01)

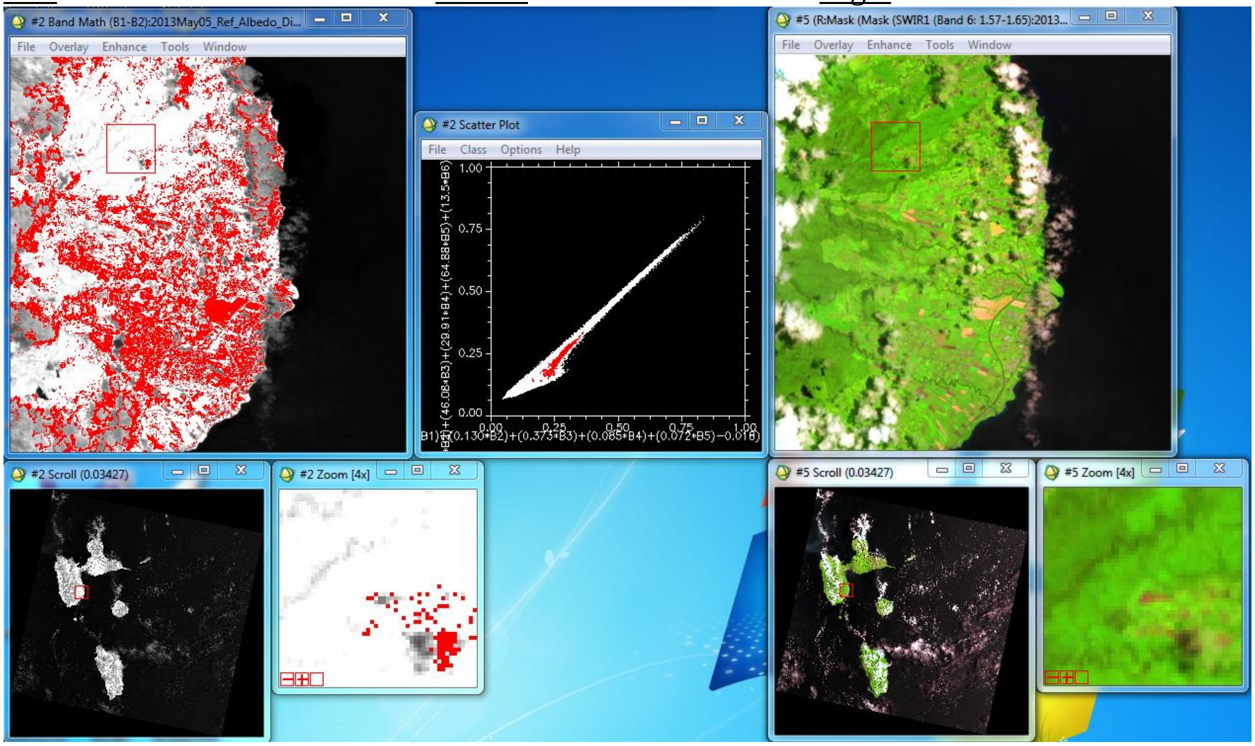
Left: Albedo Difference Middle: Scatter Plot Right: 654 - RGB



Note: Red pixels are urban areas.

- Bare Soil (0.02)

Left: Albedo Difference Middle: Scatter Plot Right: 654 - RGB



Note: Red pixels are bare soil.

❖ ***Florida:*** 2013May23_Ref_Albedo_Difference.

The albedo values are most similar for the Florida scene. Smith's values give noticeably larger albedo values for coastal waters relative to those of non-coastal waters. For other landcover, Liang's values were higher for clouds by 0.02, for agricultural fields by 0.01, for vegetation by 0.05, and for urban areas by 0.01. For bare soil, there was negligible difference.

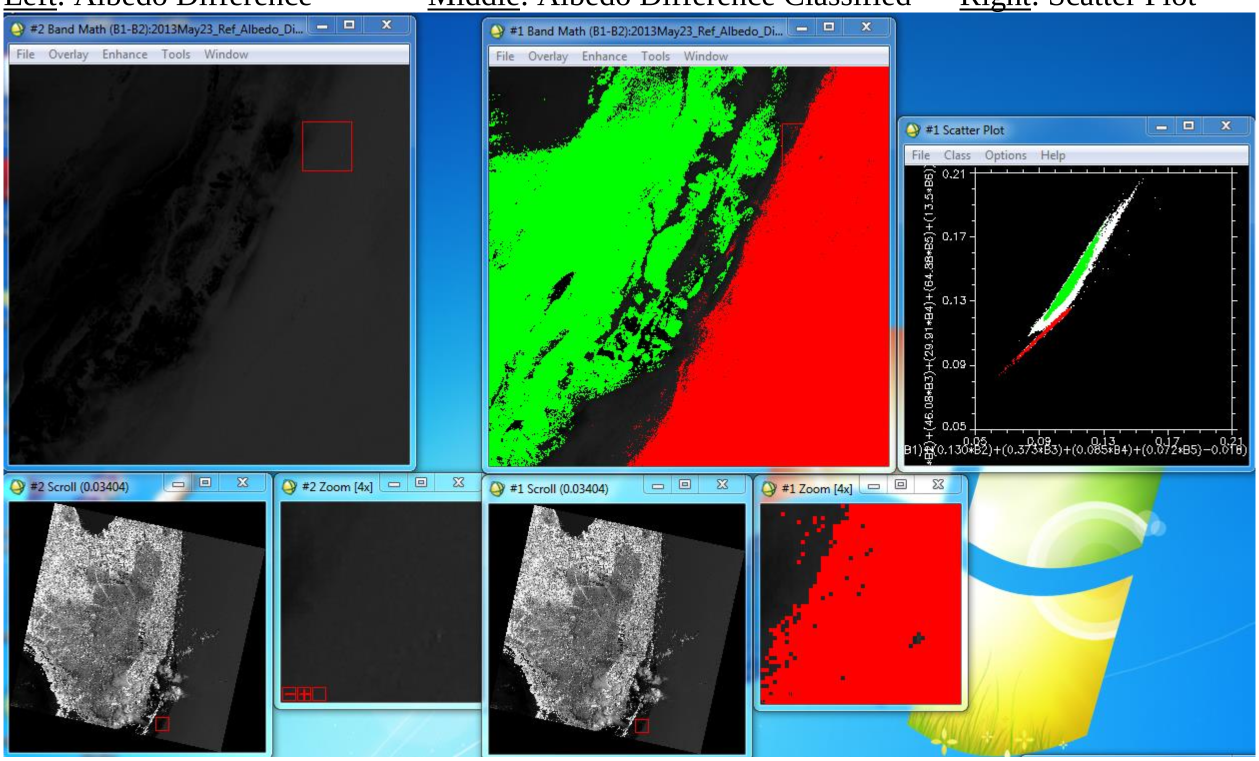
<u>Summary</u>: B1-B2 = Liang's - Smith's

	Min	**Max**	**Mean**	**St Dev**
Alaska	-0.113785	0.108876	0.025875	0.019283
Dominica	-0.075537	0.166306	-0.014645	0.016157
Florida	-0.098450	0.158823	0.003720	0.025338
Mississippi	-0.066396	0.133971	0.026451	0.030297

<u>Note</u>: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

- Coastal (Albedo Difference = -0.035) vs. Non-coastal Waters (-0.015)

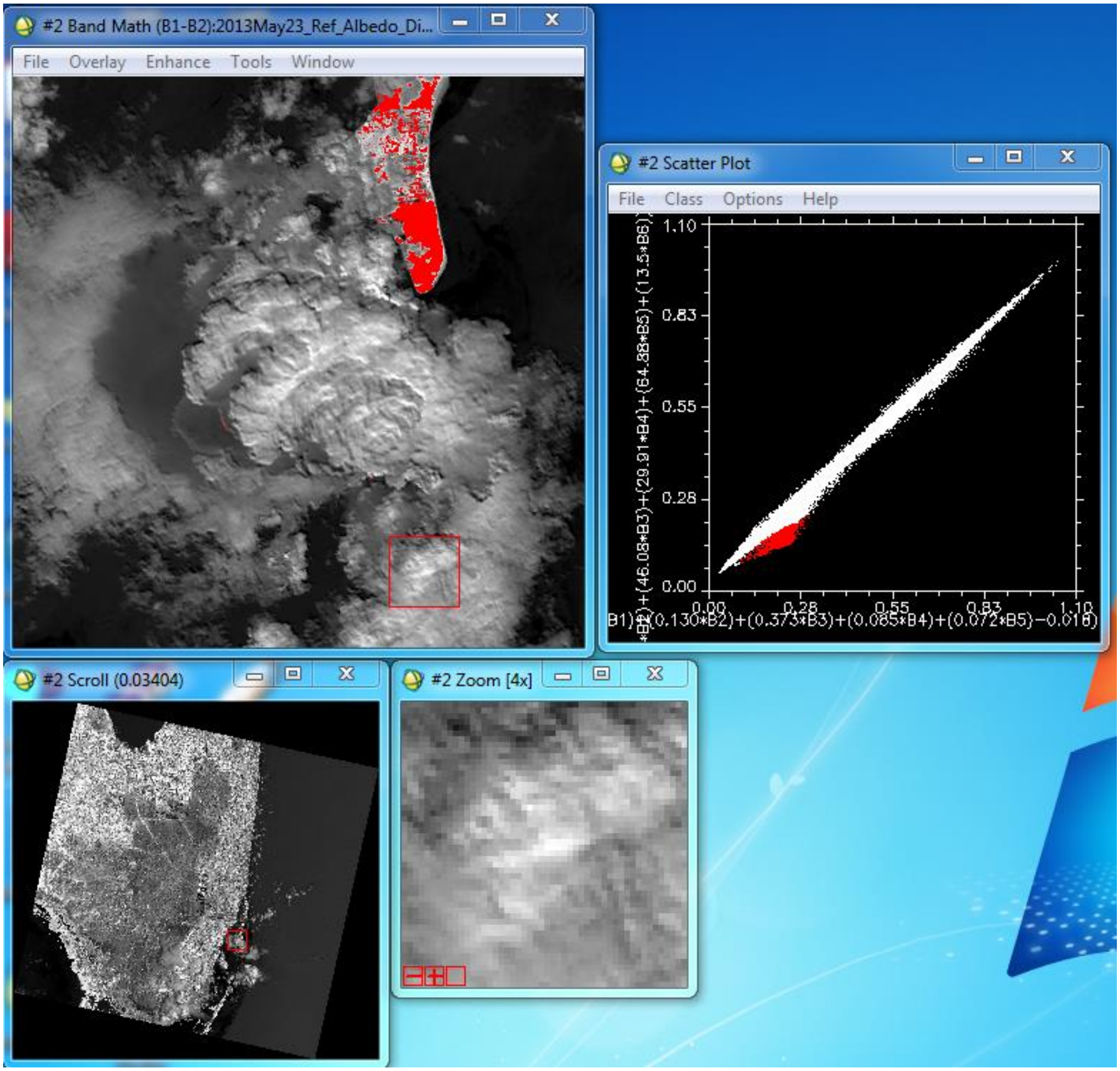
<u>Left</u>: Albedo Difference <u>Middle</u>: Albedo Difference Classified <u>Right</u>: Scatter Plot



<u>Note</u>: Red pixels are non-coastal waters, and green pixels are coastal waters.

For the coastal waters, the Smith method yields higher albedo values than it normally does for non-coastal waters.

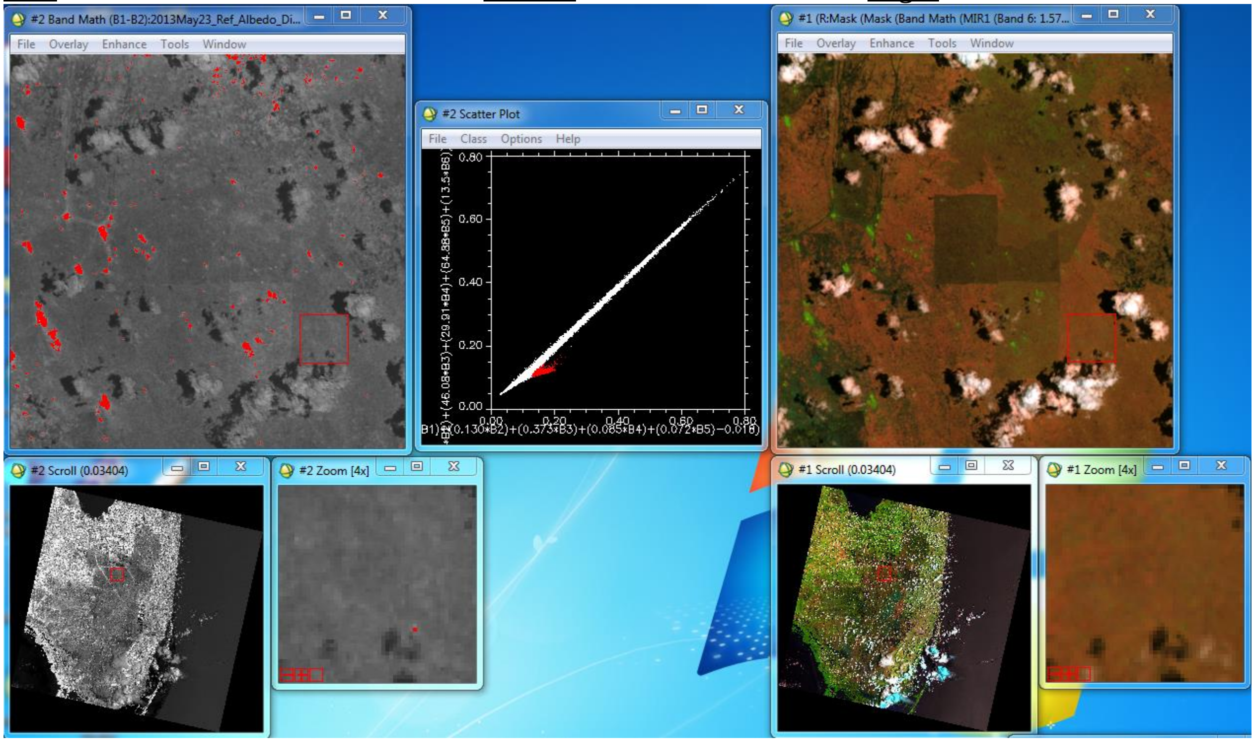
- Clouds over Water (0.02)



<u>Note</u>: Red pixels are vegetation.

- Bare Soil (0.00)

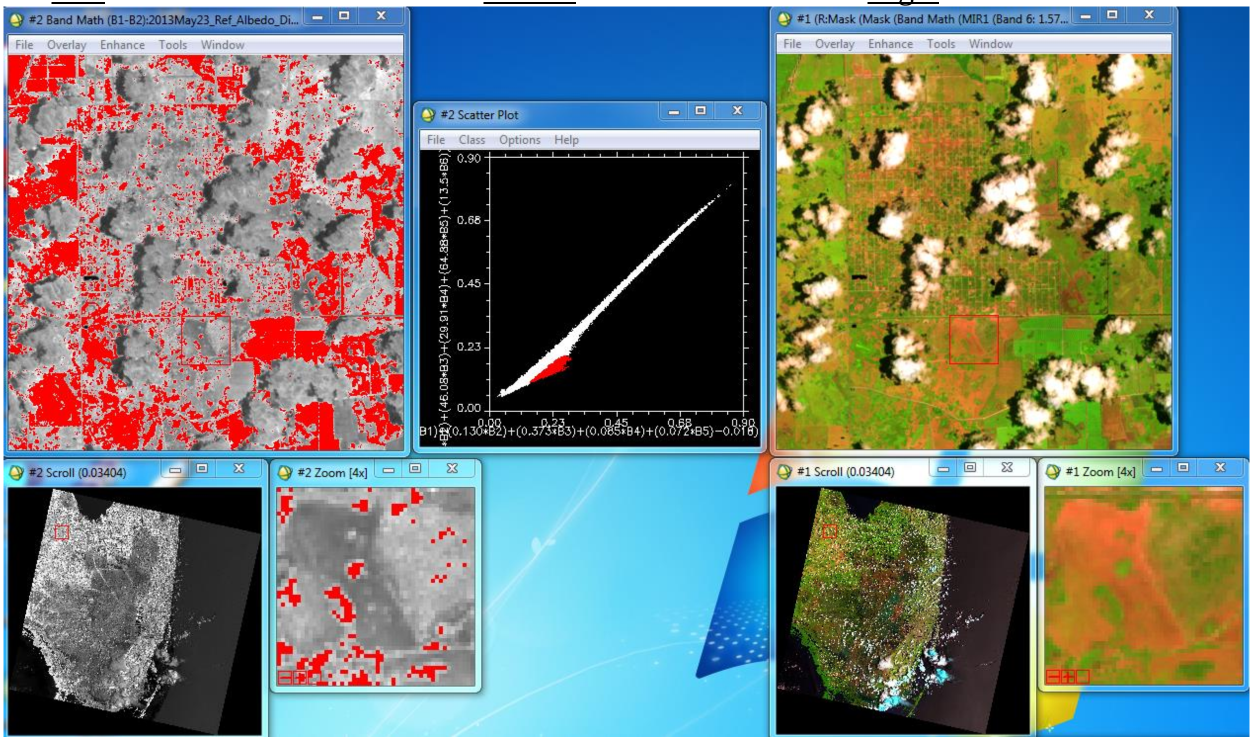
<u>Left</u>: Albedo Difference <u>Middle</u>: Scatter Plot <u>Right</u>: 654 - RGB



<u>Note</u>: Red pixels are vegetation.

- Agricultural Fields (0.01)

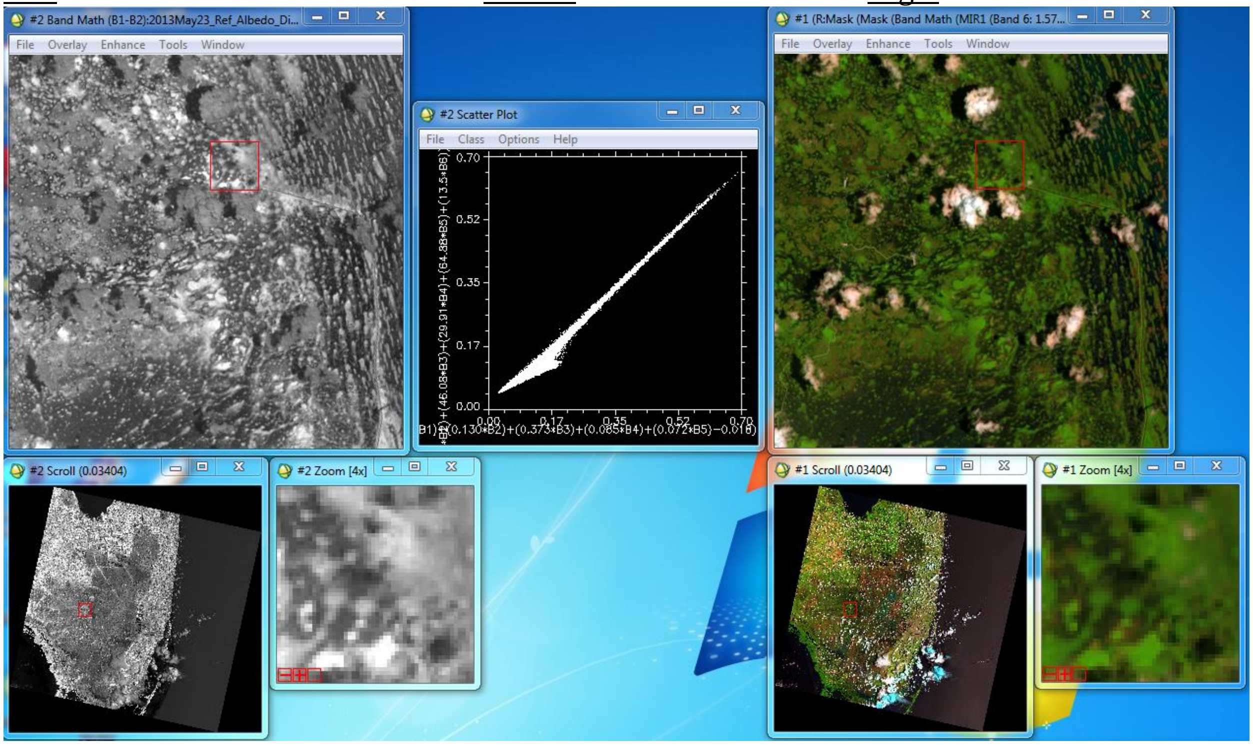
Left: Albedo Difference Middle: Scatter Plot Right: 654 - RGB



Note: Red pixels are vegetation.

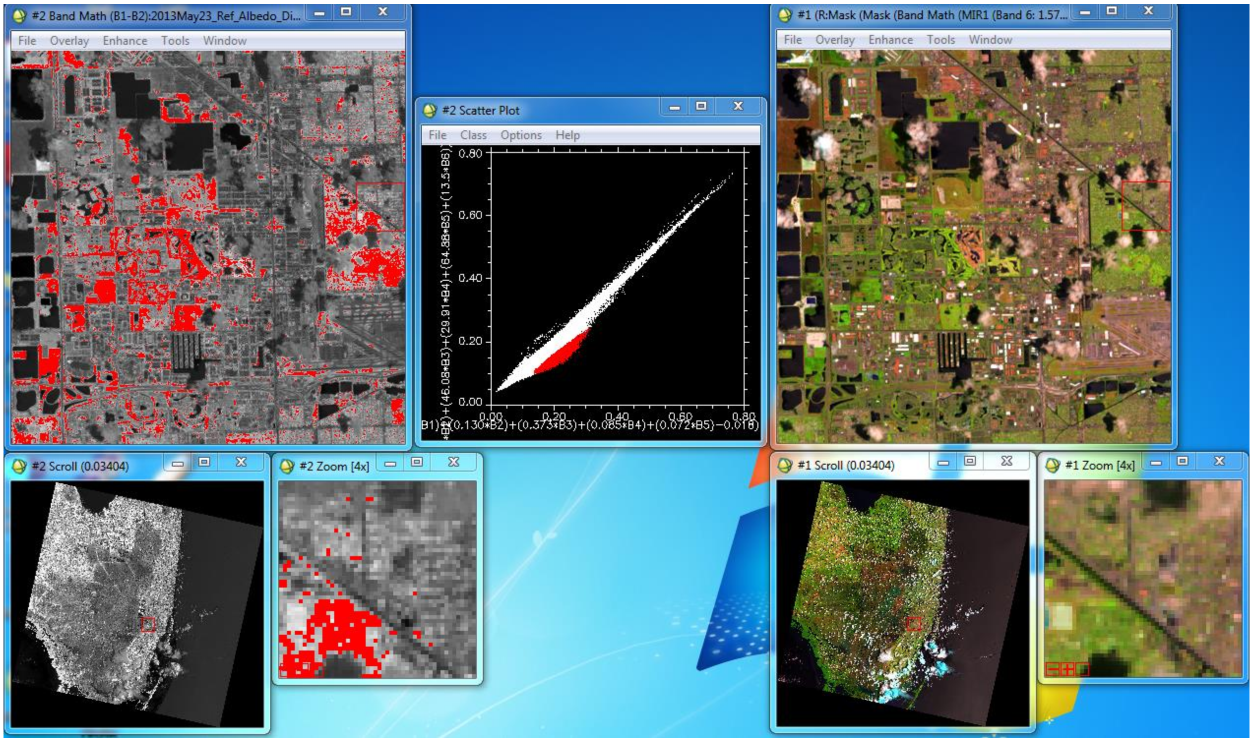
- Vegetation (0.05)

<u>Left</u>: Albedo Difference <u>Middle</u>: Scatter Plot <u>Right</u>: 654 - RGB



Urban Areas (0.01)

Left: Albedo Difference Middle: Scatter Plot Right: 654 – RGB



Note: Red pixels are vegetation.

❖ ***Mississippi:*** 2013May24_Ref_Albedo_Difference.

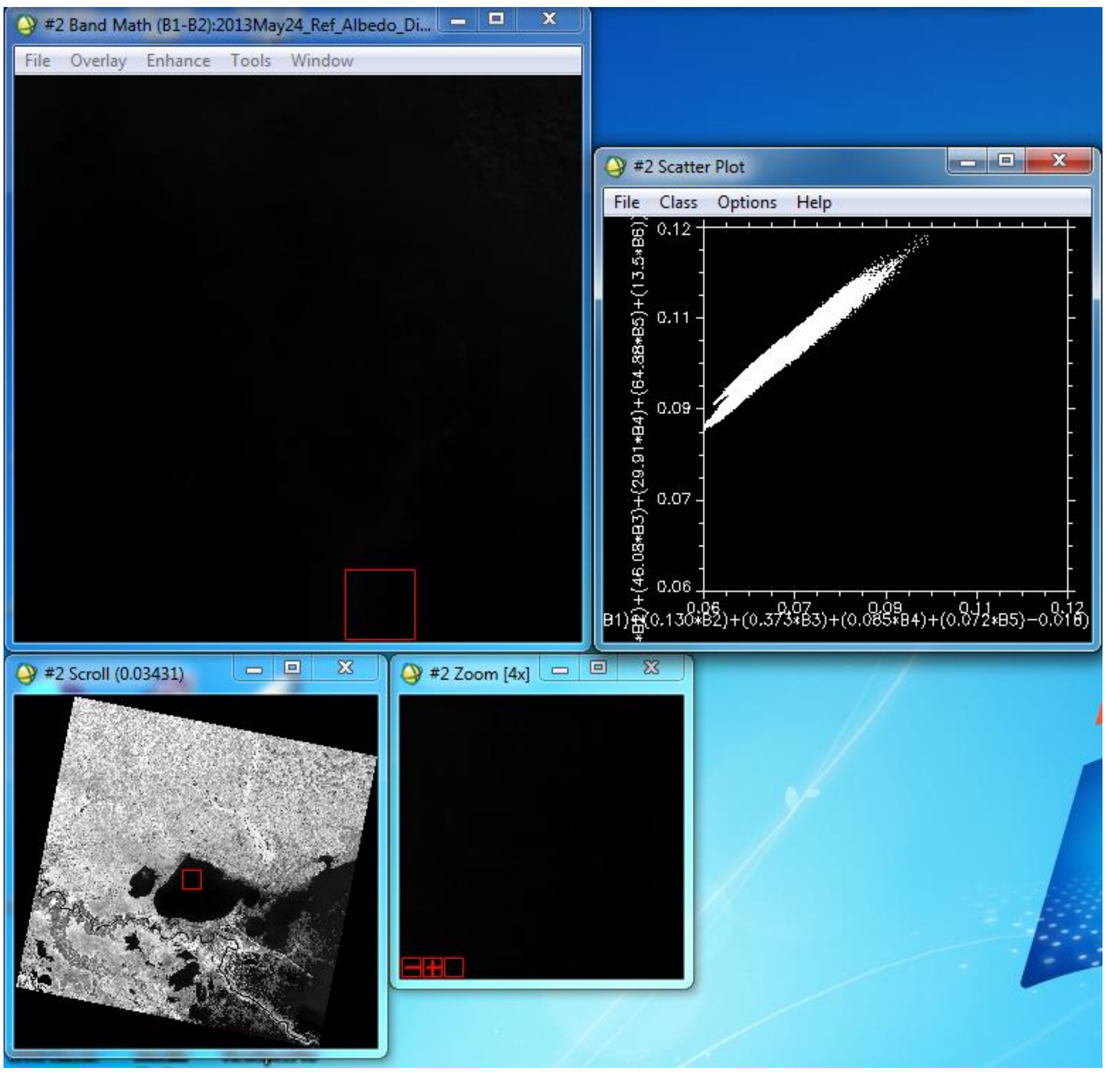
The albedo values are least similar for the Mississippi scene. Consistently across various scenes, Smith's albedo values for water are 0.02 greater than Liang's. On the other hand, Liang's values are greater by: 0.015 for urban areas; 0.025 for clouds; 0.025 for agricultural fields; and 0.035 for vegetation.

<u>Summary</u>: B1-B2 = Liang's - Smith's

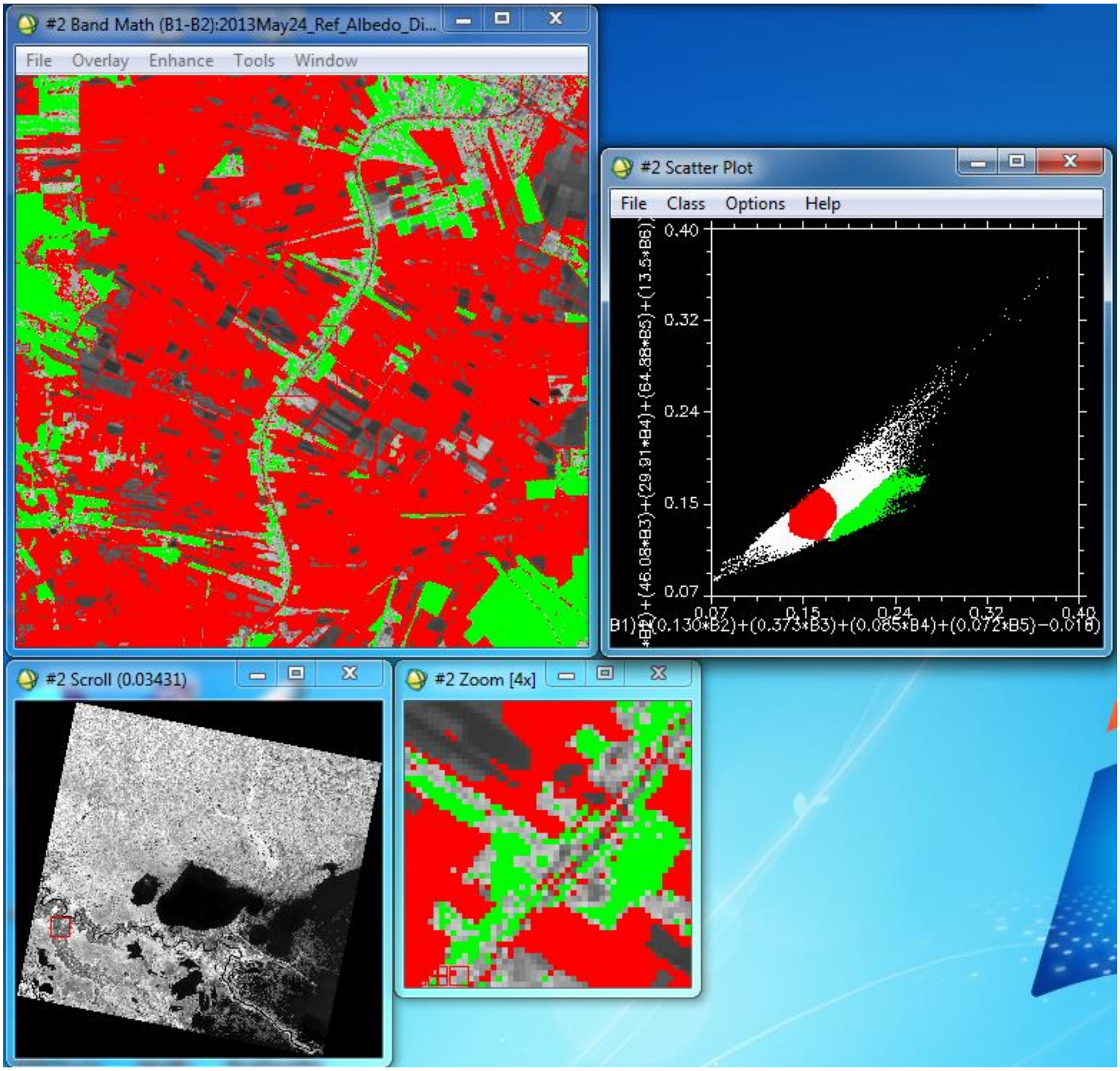
	Min	Max	Mean	St Dev
Alaska	-0.113785	0.108876	0.025875	0.019283
Dominica	-0.075537	0.166306	-0.014645	0.016157
Florida	-0.098450	0.158823	0.003720	0.025338
Mississippi	-0.066396	0.133971	0.026451	0.030297

<u>Note</u>: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

- Water (Albedo Difference = -0.02)



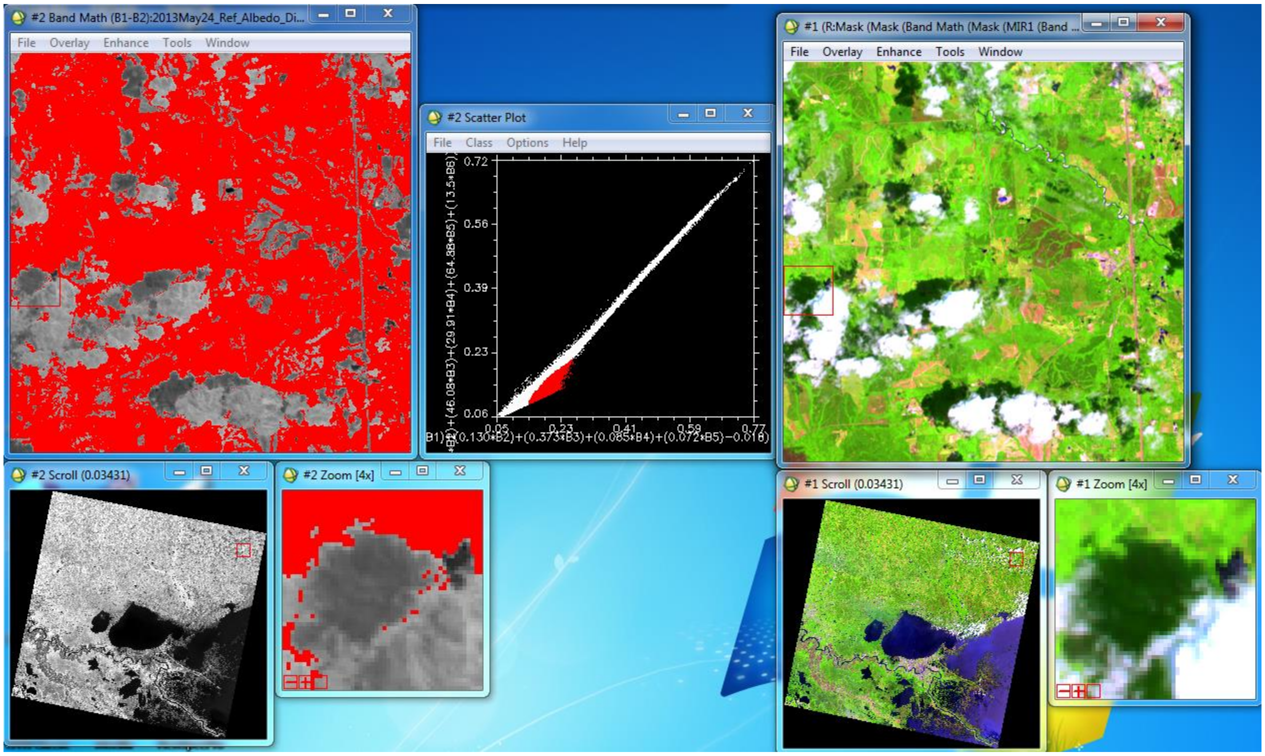
- Urban (0.015)



Note: Classes: Red = Urban Green = Vegetation

- Clouds over Land (0.025)

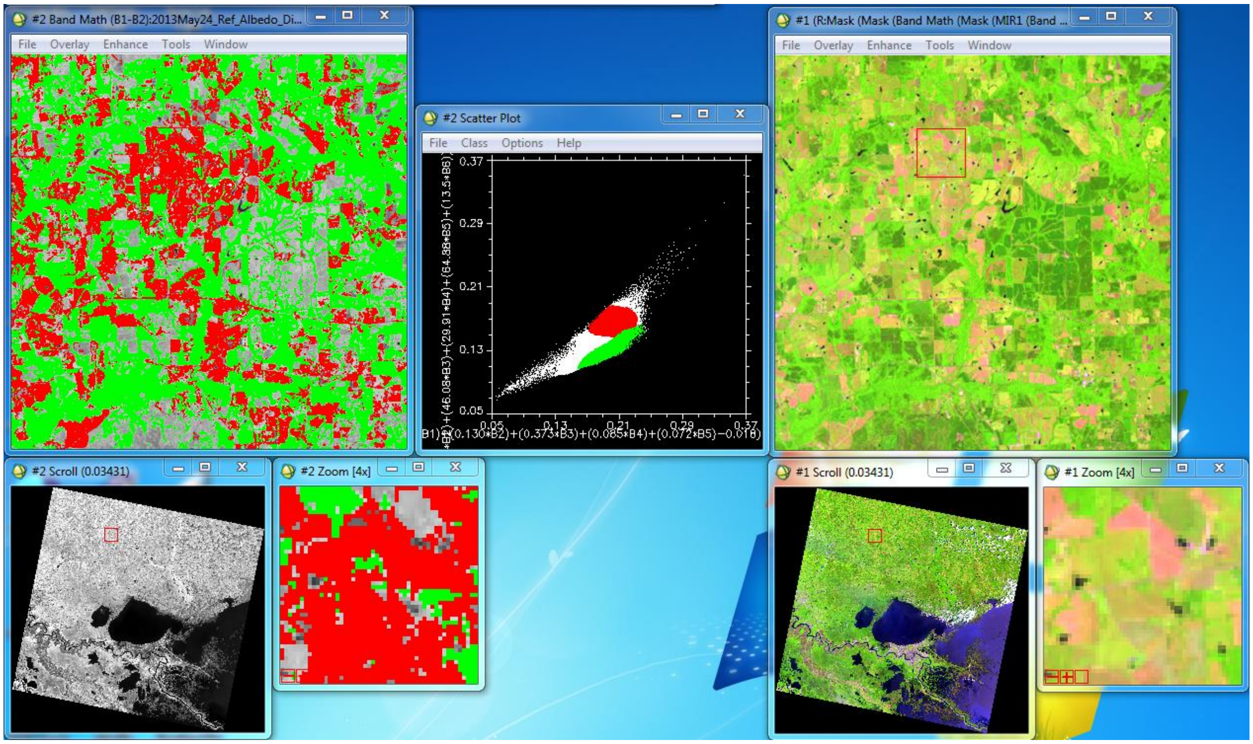
<u>Left</u>: Albedo Difference <u>Middle</u>: Scatter Plot <u>Right</u>: 654 - RGB



<u>Note</u>: Red pixels indicate vegetation

- Agricultural Fields (0.025)

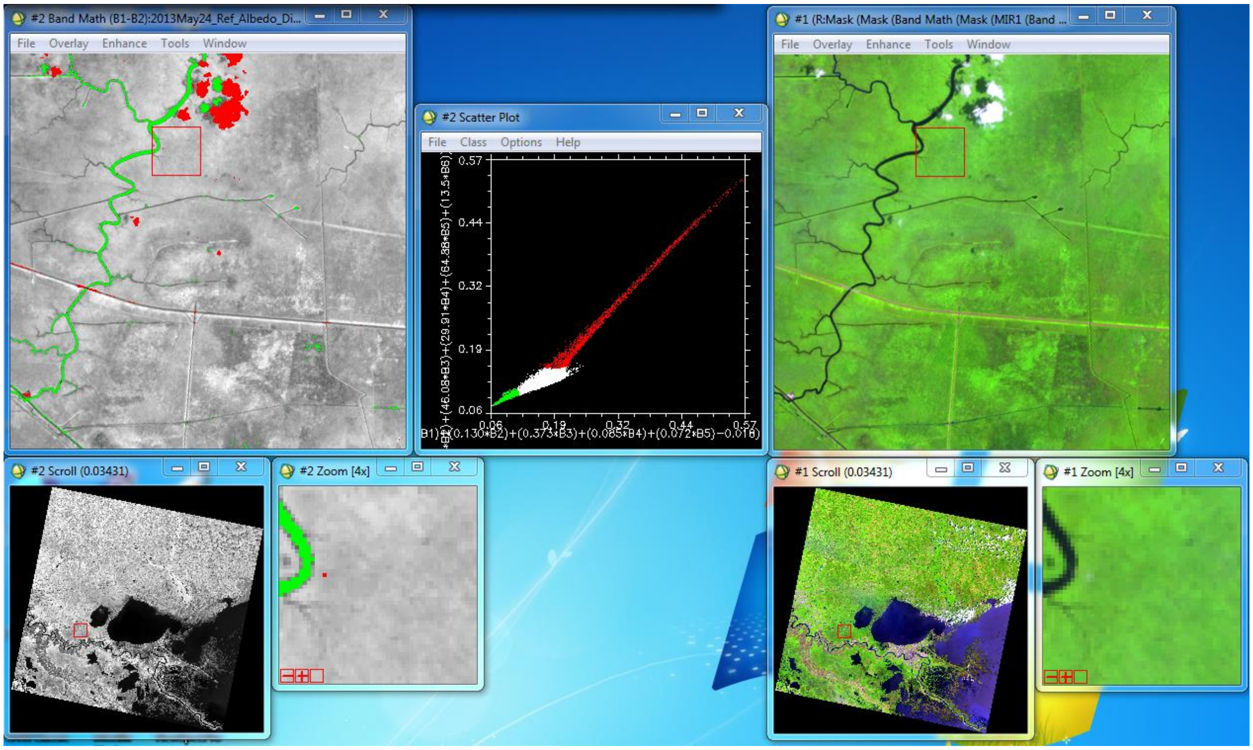
Left: Albedo Difference Middle: Scatter Plot Right: 654 - RGB



Note: Classes: Red – Agricultural Fields Green – Vegetation

- Vegetation (0.035)

Left: Albedo Difference Middle: Scatter Plot Right: 654 - RGB



Note: Classes: Red – Clouds Green – Water

Summary: Albedo Difference Consistency

B1-B2 = Liang's - Smith's

	Alaska	Dominica	Florida	Mississippi
Snow/Ice	*In Sunlight:* 0.05	-	-	-
	In Shadow:-0.02	-	-	-
	Melting Ice on the River: -0.06	-	-	-
Water	*Icy River*: 0.025	-0.02	*Coastal*: -0.035	-0.02
	-	-	*Ocean*: -0.015	-
Bare Soil	0.01	0.02	0.00	-
Clouds	-	*Over water*: 0.01	*Over water*: 0.02	*Over Land*: 0.025
Urban	-	0.01	0.01	0.015
Vegetation	-	0.07	0.05	0.035
Agricultural Fields	-	-	0.01	0.025

Note: Positive values indicate bigger Liang's albedo values than Smith's; Negative values indicate Smith's are bigger.

In shadow and water alike, Smith's method yields higher albedo values than Liang's method. Especially when the water is coastal, Ron's method yields in even higher albedo values compared to non-coastal waters such as the middle of the ocean. But, more importantly, these albedo differences are consistent at -0.02 across various scenes.

Other landcovers that are consistent in albedo difference are bare soil at 0.01 and urban areas at 0.01. Clouds are a bit more variant at 0.02.

Vegetation and agricultural fields show the biggest and the least consistent albedo differences across various scenes. For example, vegetation in the Dominica scene has an albedo difference of 0.07 while the Mississippi's scene has 0.035.

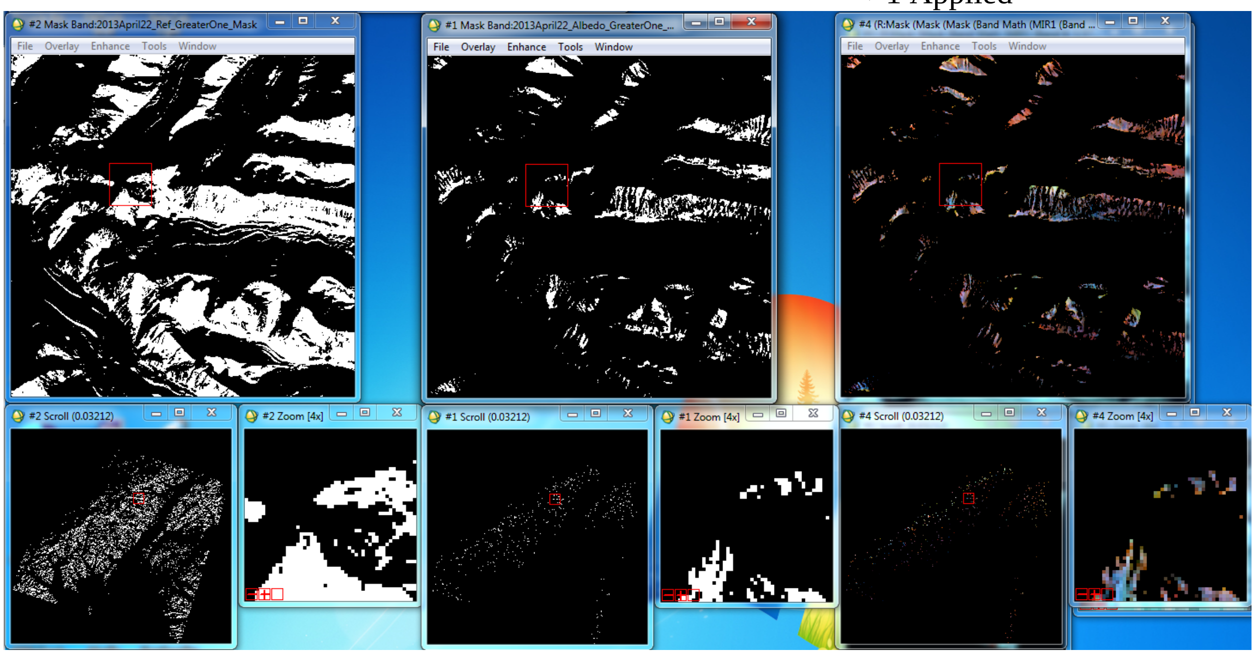
Greater than One Albedo

As previously mentioned, all of the scenes have albedo values greater than 1 for both Liang's and Smith's methods. In order to confirm if these greater than one albedo values are due to greater than one reflectance values, I conducted the following analysis: 1. I compared masks for both greater than one reflectance and albedo values. 2. Then, I applied the mask for greater than one albedo pixels on the TOA file, and then computed statistics for the masked pixels.

The overall results showed the greater than one albedo pixels are a subset of the greater than one reflectance pixels, usually consisting of the pixels with the highest reflectance values.

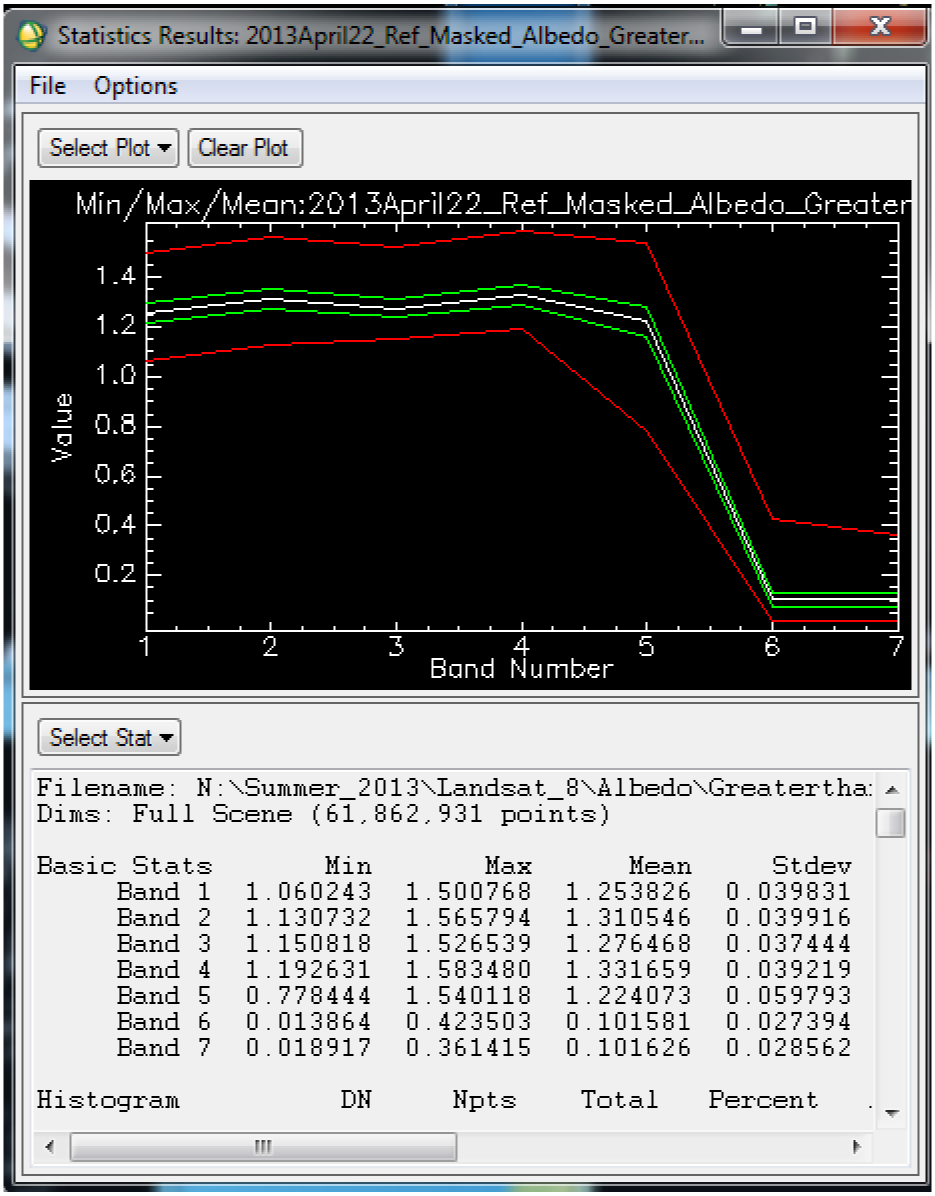
- *Alaska: 2013April22_Albedo_GreaterOne_Mask*

Left: Mask for Reflectance >1 Middle: Mask for Albedo >1 Right: Reflectance (654-RGB) with Mask for Albedo >1 Applied



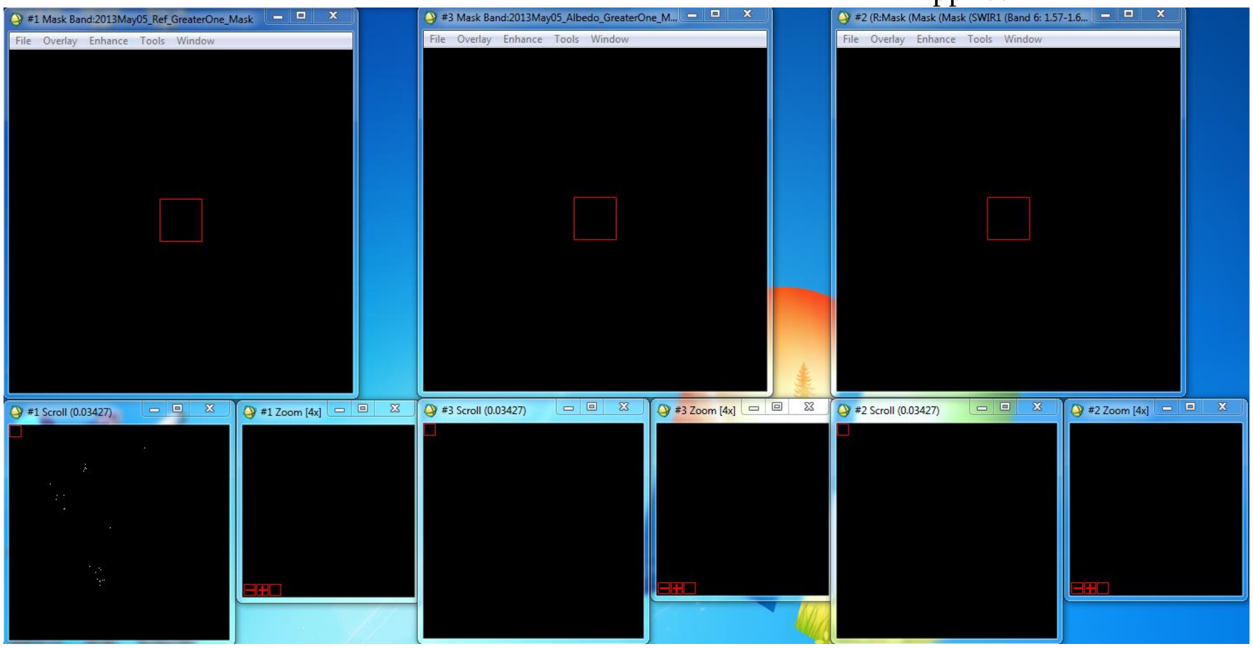
It is important to note that the number of greater than one albedo pixels found in the northern parts of the mountain ridge is much smaller than those found on the southern east facing, snow-covered slopes (See middle Scroll window).

Below is the Statistics Output for “Reflectance (654-RGB) with Mask for Albedo >1 Applied” – the reflectance file which was masked for pixels that had greater than 1 albedo values. As results show, the greater than one albedo pixels most probably had greater than one reflectance value in at least one of the bands: the minimum reflectance values for these pixels on Bands 1-4 are greater than one.



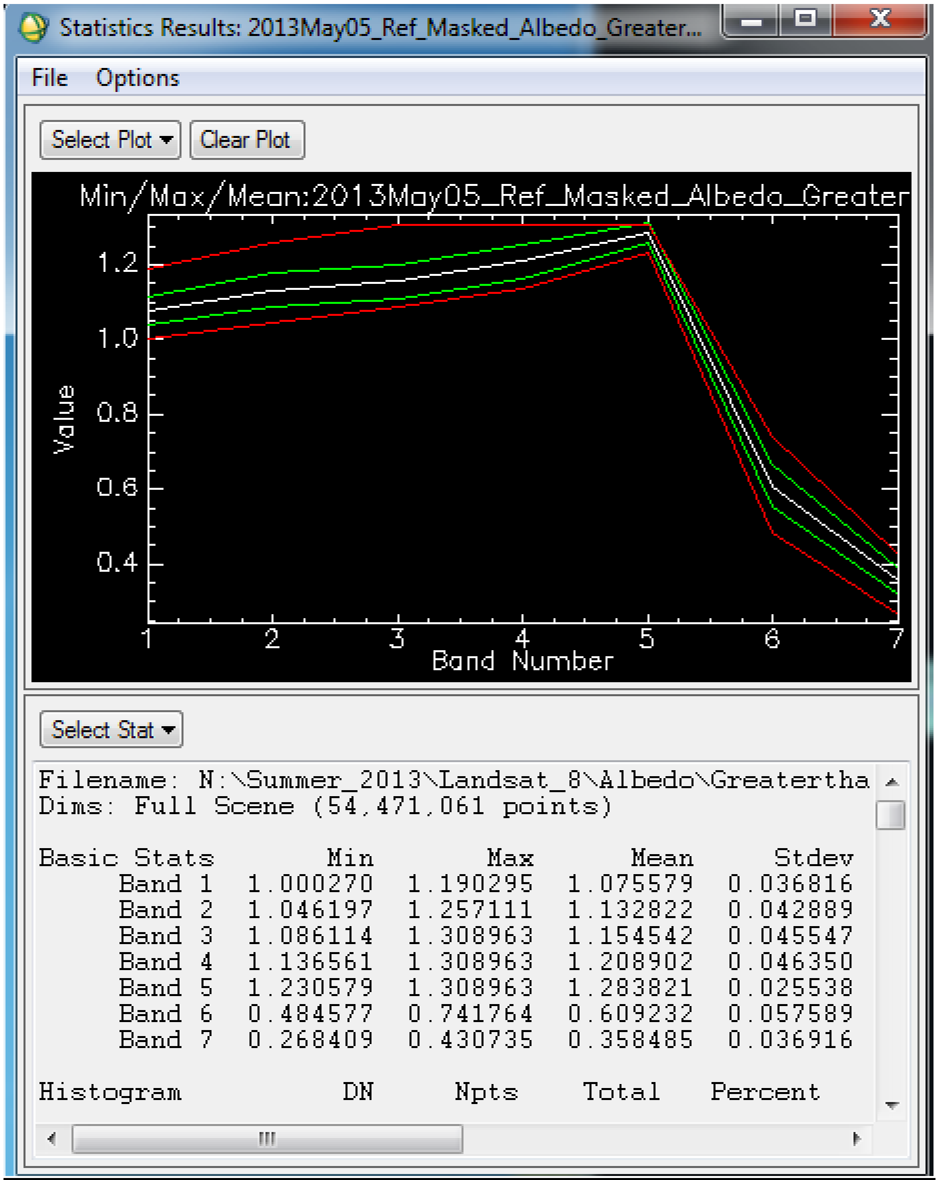
- *Dominica: 2013May05_Albedo_GreaterOne_Mask*

Left: Mask for Reflectance >1   Middle: Mask for Albedo >1   Right: Reflectance (654-RGB) with Mask for Albedo >1 Applied



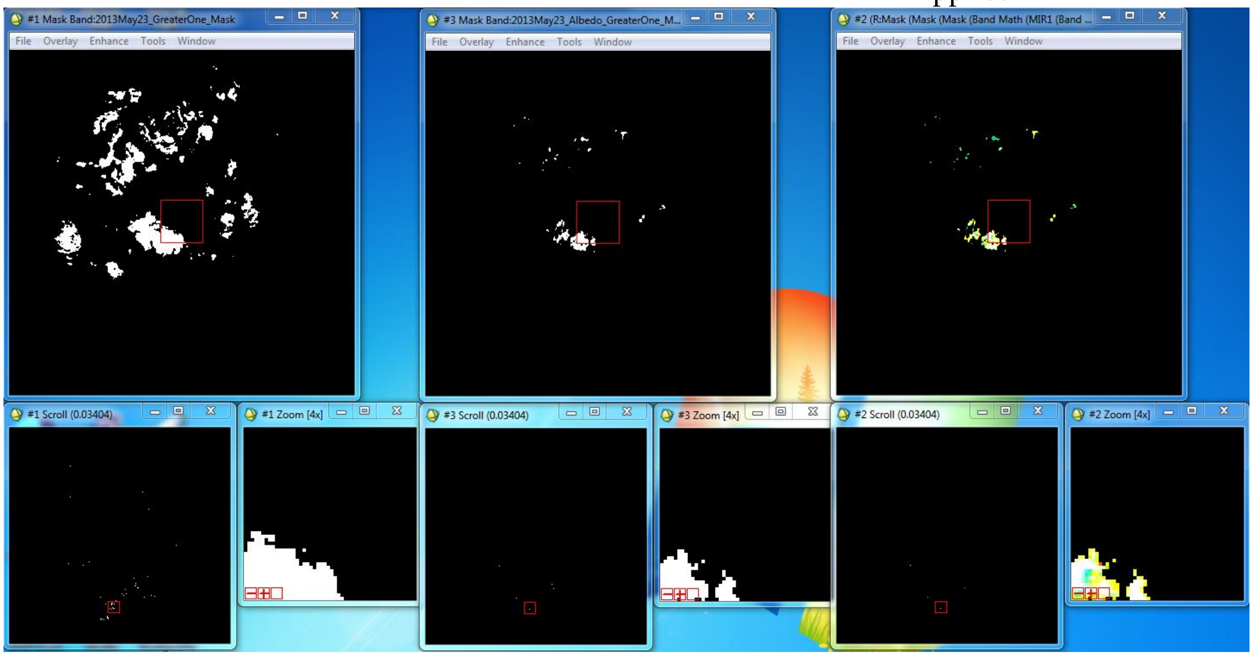
The masked pixels are too few to see them clearly in the images above. For example, the second and third images should both have 168 white pixels.

Below is the Statistics Output for “Reflectance (654-RGB) with Mask for Albedo >1 Applied.” Note that the minimum reflectance values on Bands 1-5 for these specific pixels are greater than one.



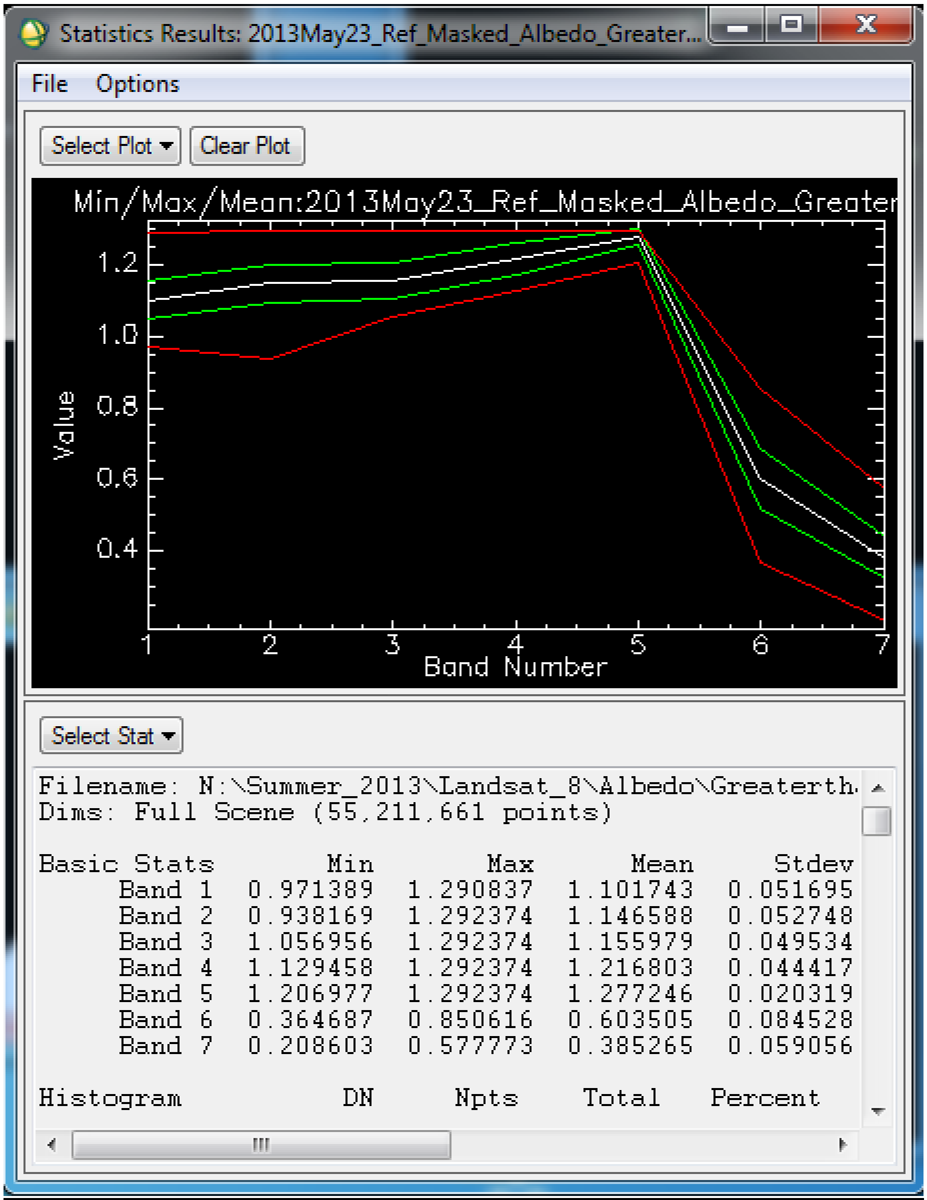
❖ *Florida: 2013May23_Albedo_GreaterOne_Mask*

Left: Mask for Reflectance >1   Middle: Mask for Albedo >1   Right: Reflectance (654-RGB) with Mask for Albedo >1 Applied



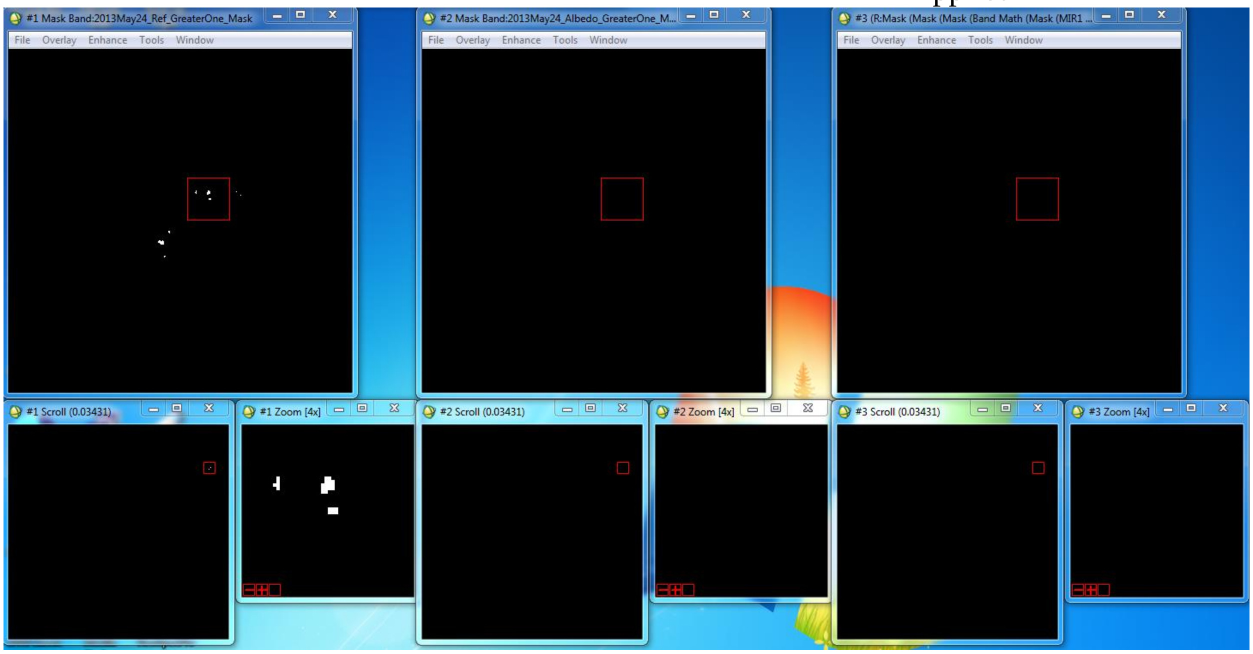
The Florida scene shows that the greater than one albedo pixels are found in areas of cloud pixels.

Below is the Statistics Output for "Reflectance (654-RGB) Mask for Albedo >1 Applied." Note that the minimum reflectance values on Bands 3-5 for these specific pixels are greater than one.



❖ *Mississippi: 2013May24_Albedo_GreaterOne_Mask*

<u>Left</u>: Mask for Reflectance >1 <u>Middle</u>: Mask for Albedo >1 <u>Right</u>: Reflectance (654-RGB) with Mask for Albedo >1 Applied



The masked pixels are too few to see them clearly in the images above. For example, the second and third images should both have only 4 white pixels.

The number of greater than one albedo pixels corresponds to the level of cloud coverage in landscapes devoid of ice and snow. For example, Mississippi has the lowest cloud coverage and also the smallest number of greater than one albedo pixels.

Below is the Statistics Output for “Reflectance (654-RGB) Mask for Albedo >1 Applied.” Note that the minimum reflectance values on Bands 4 and 5 for these specific pixels are greater than one.