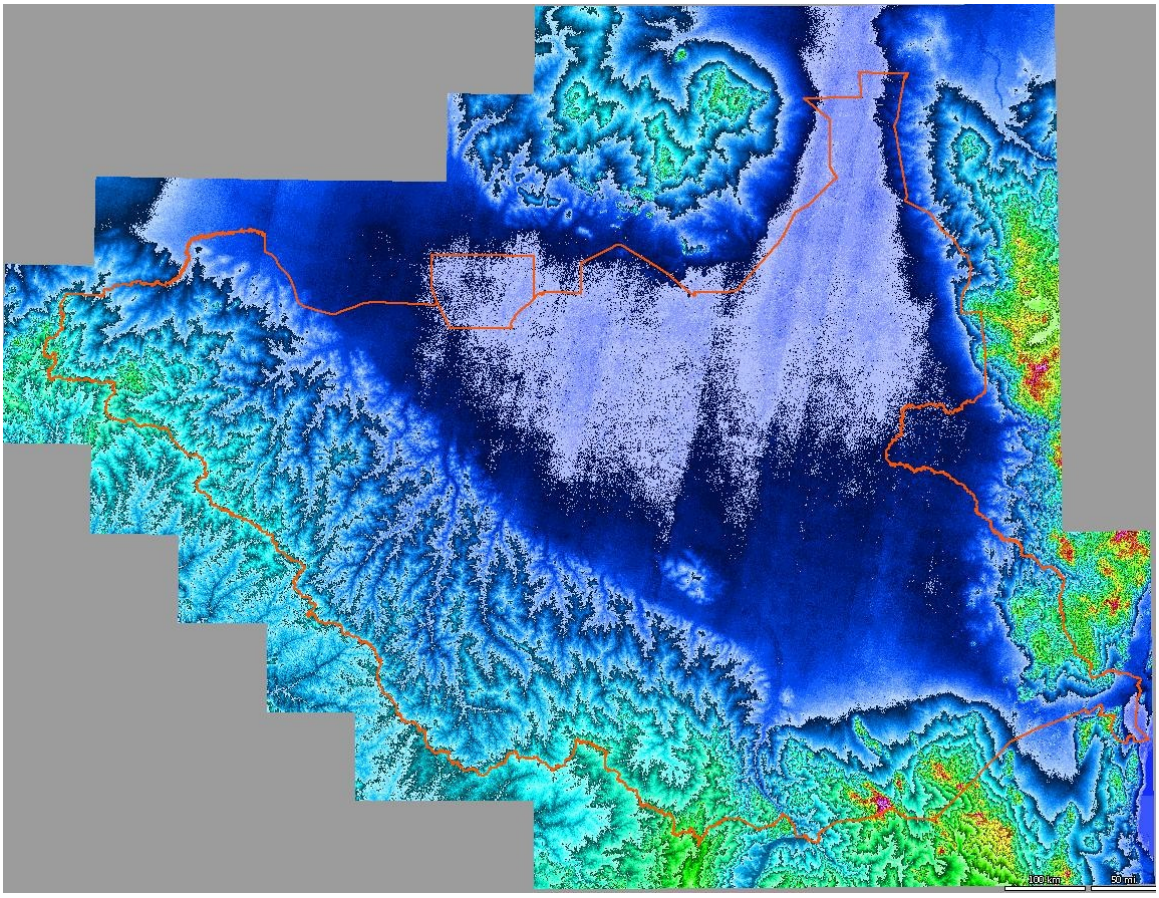
South Sudan - First Impressions

I am Dr. Edmond W. Holroyd, III, or simply Ed Holroyd. Educationally, I have a B.S. in astrophysics, a Ph.D. in atmospheric science, and non-degree continuing education in geology. I am also a bird watcher and have seen in the wild more than one eighth of the world's bird species, photographing many of them. I am now retired and at age 77. In most of my career I did weather research and modification experiments for CSIRO in Australia (3 years) and the United States Bureau of Reclamation. Later I specialized in remote sensing research, viewing the Earth from aircraft and satellite and analyzing the imagery. My time with Reclamation was 31 years. Overlapped with that, for more than 17 years I taught graduate courses in remote sensing for the University of Denver.

For many decades I was aware of the difficulties in southern Sudan. Awareness increased when Arok Garang, one of the "Lost Boys", became a member of our former church congregation, Arvada Covenant Church in Arvada, Colorado. He founded an organization, Seeds of South Sudan (www.SeedsOfSouthSudan.org), to move South Sudan refugee children, living in Kakuma, Kenya, and educating them in Nakuru, Kenya, to become future leaders in South Sudan. My wife and I have recently become sponsors of one of those children.

A 3-part trip of Seeds supporters is being organized, subject to COVID restrictions, for next September, to visit Nairobi, Nakuru, and Kakuma. My wife and I visited the highlands of Kenya for several days in March, 1970. My older daughter and future husband, for their medical doctor preparations, did their tropical medicine experiences in a bush hospital in Kapsowar with visits to Eldoret hospital in Kenya, in January-February 2005. I am eager to return to Kenya and am doing various studies in preparation.

Though the trip will not include a visit to South Sudan, I decided to use my remote sensing skills to learn much about the country. Google Earth provides both overviews and resolutions in some areas fine enough to see individual trees, cars, and homes. I extracted the country borders from Google Earth, though other maps show different border positions in some regions. This initial report shows some of what I am learning.

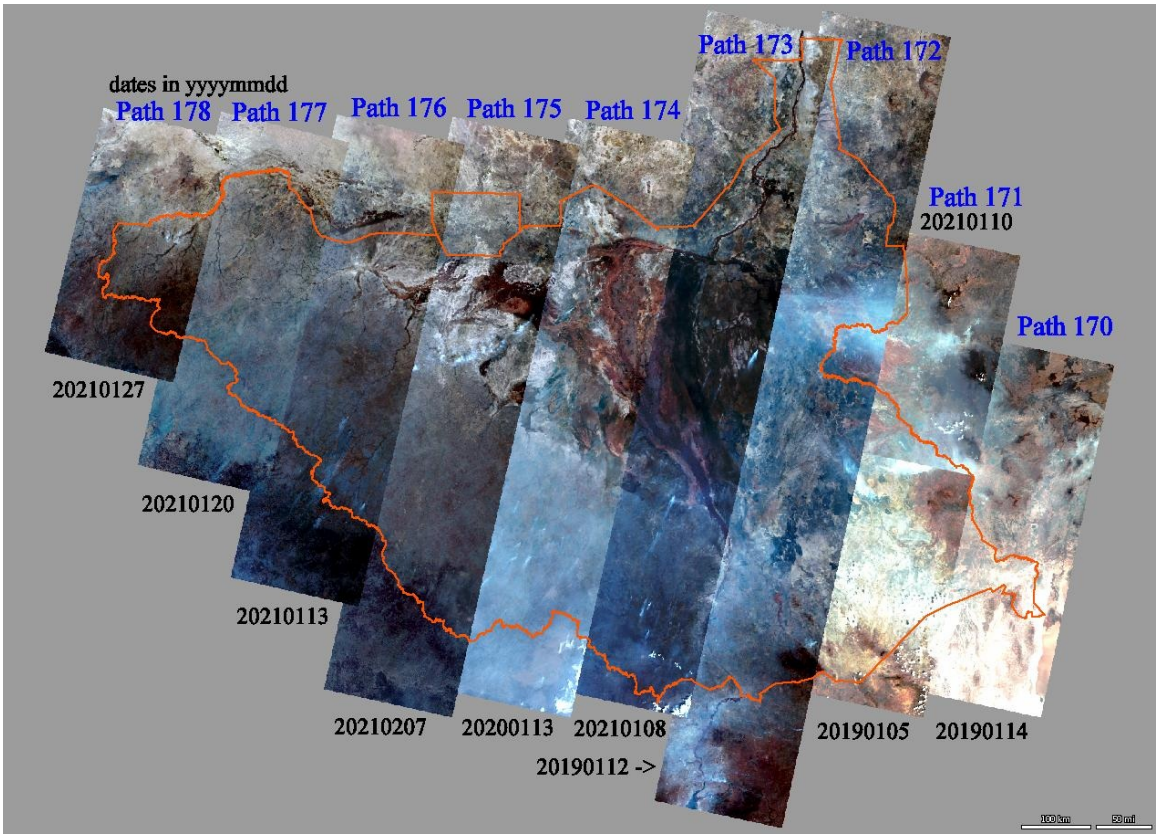


Using elevation data from the ASTER satellite data I have made this colorized contour map with an orange country border. Bluish (both light and dark) colors are for lowest elevations, going to reds for highest elevations.

The country is like a basin of lowlands surrounded by high terrain. The Nile River flows through from south to north.

Google Earth shows most of South Sudan as green, so its imagery was likely taken during cloud-free periods of healthy vegetation.

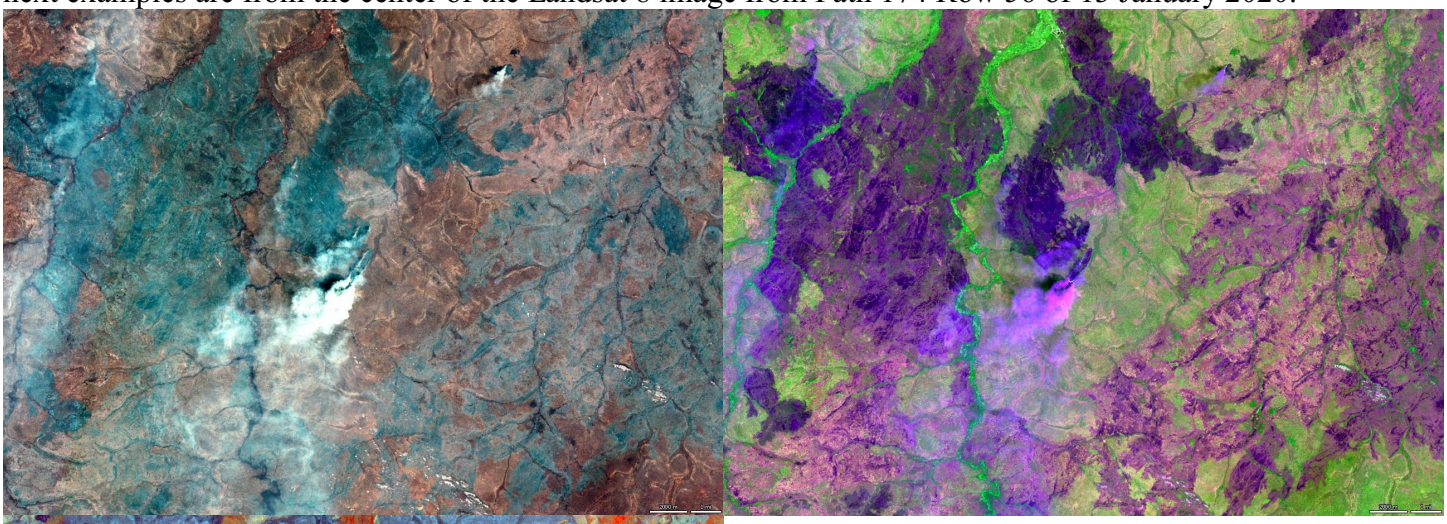
I downloaded a set of images from the Landsat 8 satellite. I chose dates in January and some February, the dry season, to minimize coverings of soils and rocks by green vegetation. I also chose images with minimal to no cloud cover. The Landsat images are organized by sequential Paths around the world and Rows (numbered from north to south). I also chose imagery with continuous coverage from north to south on the same date (with one exception) for perfect continuity between images. Same-day coverage across the entire country, however, is impossible. The next picture shows a false color image made from original blue and green bands. The dates for the various swaths are shown in yyyymmdd format.



The bluish haze is mostly from smoke, with some brighter smoke plumes visible at full resolution. Some of the white in the east is from clouds. Desert areas in the southeast are bright white.

Landsat 8 has 11 spectral bands, most at 30 meters horizontal resolution. Some are in the visible bands and others in the near, short wave, and thermal infrared bands.

Band1-coastal blue: good for water penetration and smoke. Band2-blue. Band3-green. Band4-red. Band5-near infrared: healthy vegetation is very bright. Band6 and Band7 are in the short-wave infrared spectrum. Band8 is panchromatic (B&W) in the visible and near infrared spectra and at 15 meter resolution. Band9 is sensitive to thin cirrus cloud cover. Band10 and Band11 are in the thermal infrared spectrum. Fire flames show up well in bands 6, 7, 10, 11, while those bands do not show smoke but look through it to the surface. These bands can be combined various in the Red-Green-Blue display colors as false-color images to reveal particular features. The next examples are from the center of the Landsat 8 image from Path 174 Row 56 of 13 January 2020.

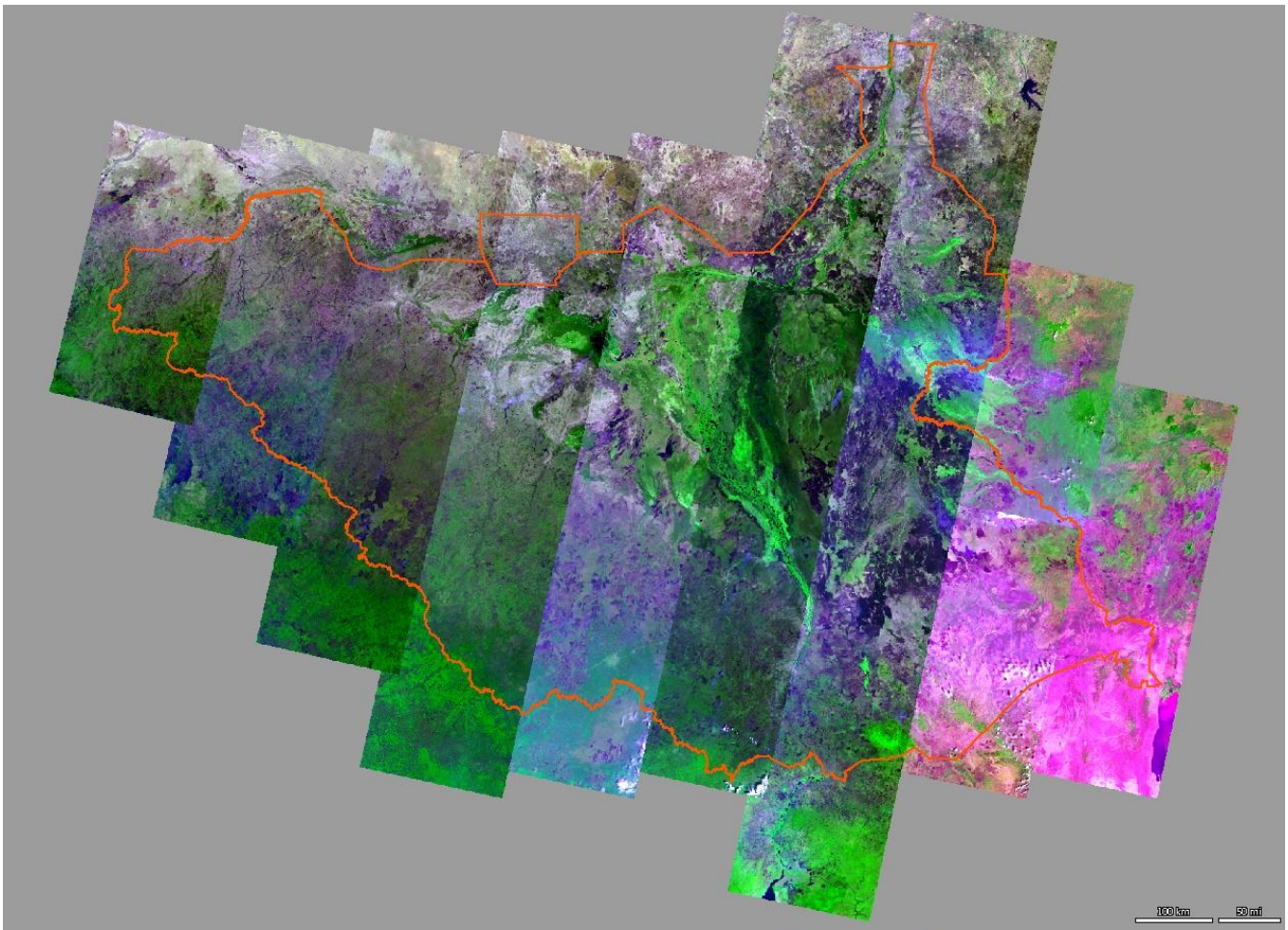


The upper left image uses bands 3,2,1 in the RGB order. White are smoke plumes. Blue-gray are burned areas. Tan is good vegetation. The upper right image uses bands 4,5,2 in the RGB order. If it was 4,3,2 it would show natural color, but I substituted band5 for green to emphasize the green vegetation. Freshly burned areas are almost black. Formerly burned areas are purple. The lower left image uses bands 10,7,6 in the RGB order. Near the center the yellow-white spots are fire flames, and there are others around the rims of the red freshly burned areas. Previously burned areas are orange and pale yellow. Unburned vegetation is blue. Rivers are dark blue. Displaying the thermal band10 as red makes hot areas red and cool areas blue.

The width across this scene is 38.8 kilometers. The original scenes show much more fire and landscape detail at 30 meter pixel resolution. These are uncontrolled fires that are doing major damage to the environment. They are greatly in excess of what might be needed for slash-and-burn agriculture. Being the dry season, such fires may be set by humans. Perhaps some are lingering fires from lightning strikes months earlier during the rains.

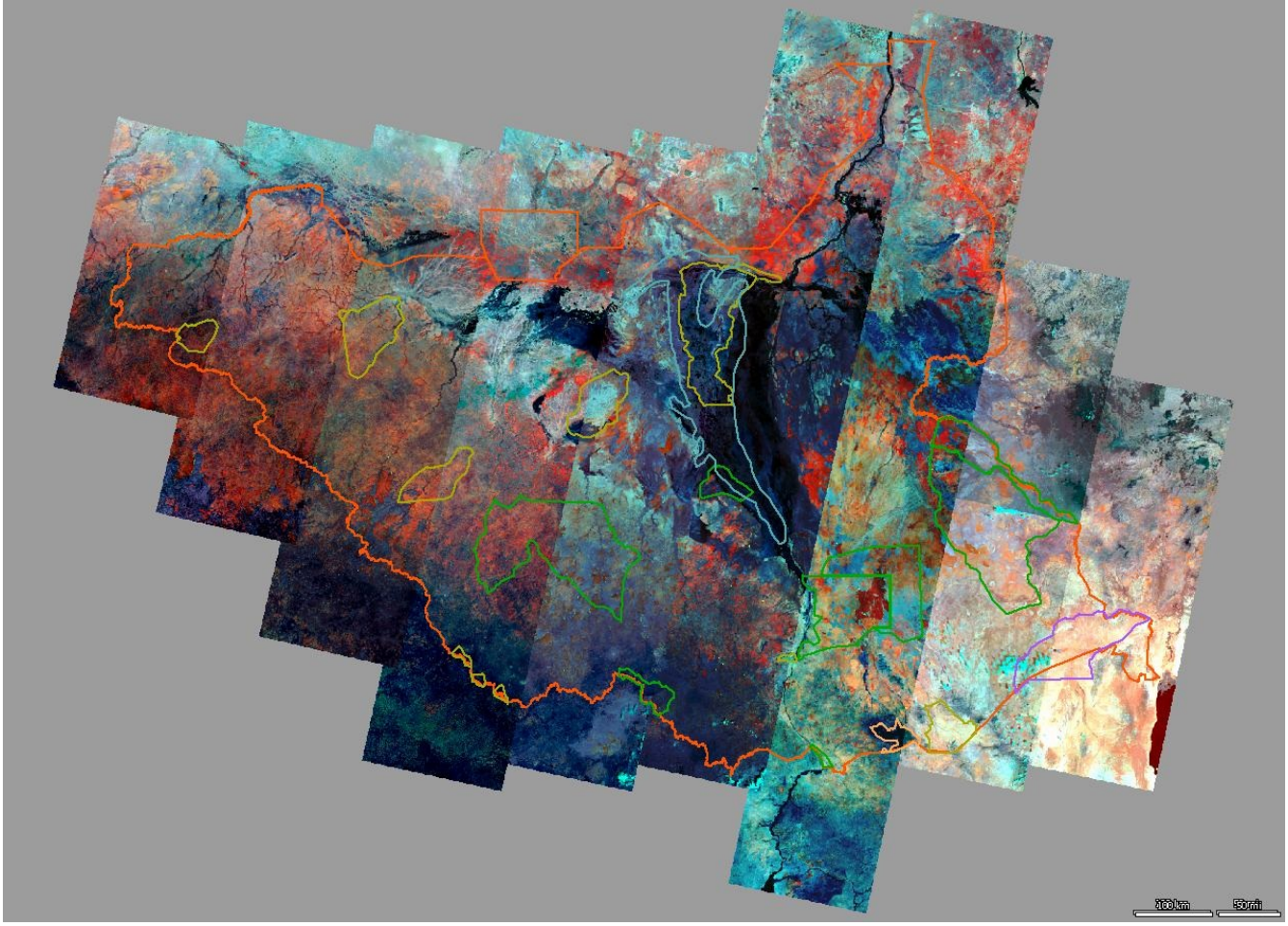
The next image shows the entire country of South Sudan in the band 4,5,2 combination. Healthy vegetation during the dry season is bright green.

After that is the band 10,7,6 combination. Red areas are freshly burned, with orange and yellow being burned in previous years. The country border and the borders of protected areas (parks, refuges) are overlaid. The 4 western swaths are all from 2021. The eastern swaths have mixed years.



4,5,2

green veg.



10,7,6

red - burn areas

In order to quantify the fire and burned landscape observations, the Landsat 8 imagery was cropped to be within the maximum borders of South Sudan (recognizing that various maps show different boundaries in a few areas.) That resulted in an area of 658,661 km^2. The analyses, by individual Paths, resulted in an area of 736,656 km^2 because of Path overlaps of nearly 12 percent.

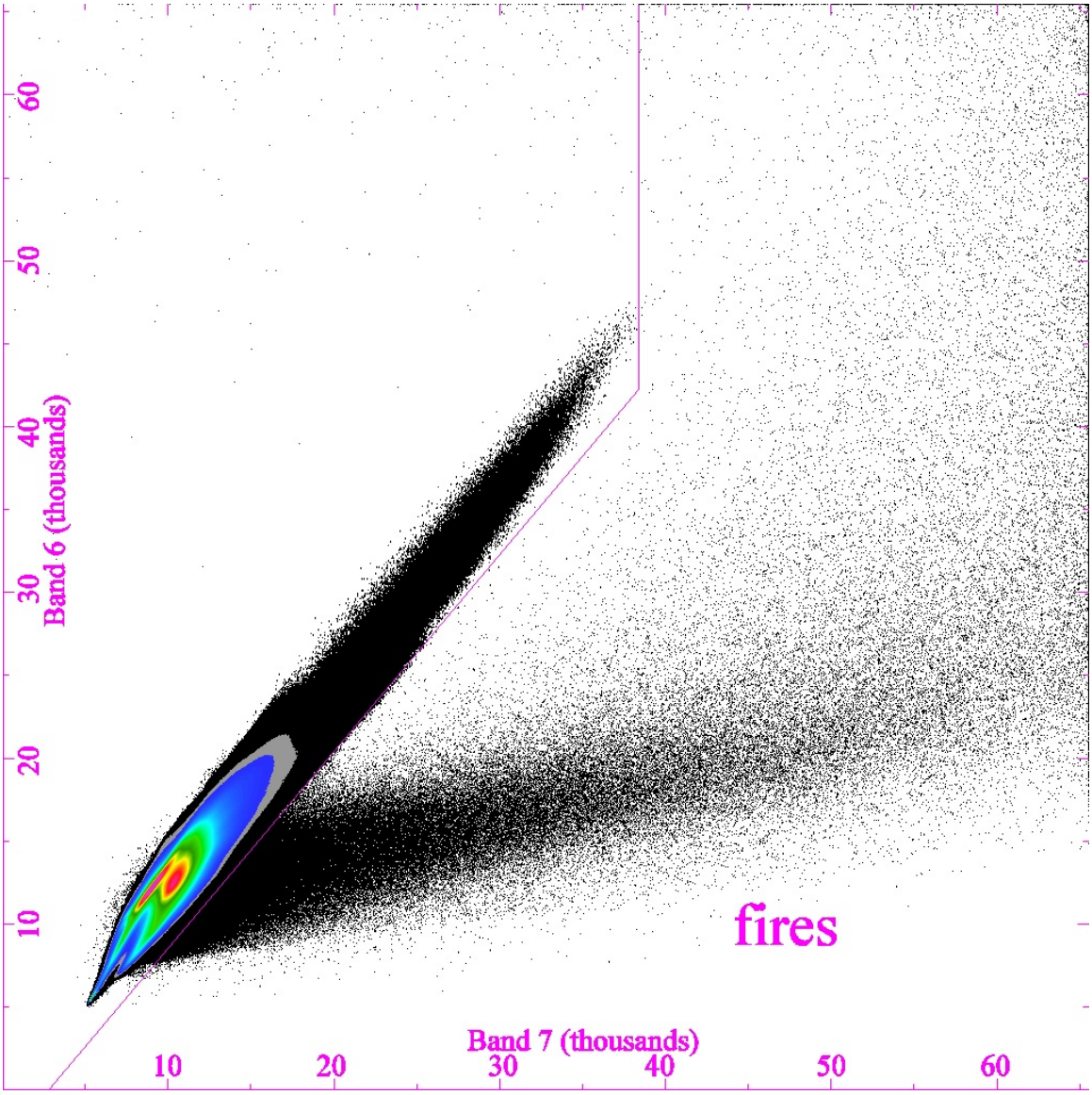
In evaluating remote sensing imagery it is important to have a variety of resolutions available. Landsat 8 imagery is at 30 m for most bands, and 15 m for the panchromatic band. Google Earth imagery can be expanded to a full range of resolutions limited only by the original image versions. For a selection of fine resolution images of surface cover I made screen captures at half-degree latitude/longitude locations throughout the country (and occasionally a little beyond) and at an indicated viewing height of 2000 feet. When calibrated the resolution calculated as 0.44 m/pixel and the scene extends 0.69 km east-west and 0.43 km north-south. The following extra image (not at a 0.5 degree location) at that resolution is from Juba to show the details available.

The above image at the same dimensions is the northern part of the screen capture at N 7.0, E 32.5. It shows huts and corrals on the left, trails, healthy trees and shrubs, and new and former burned areas.

At each of those geographic points the view was enlarged to an indicated viewing height of 20 miles. That produced a view of 22.9 x 37.3 km. If Google Earth revealed any submitted photos from the ground level within that area, those images were captured and saved for further documentation, especially of plant types and ground cover. These helped interpret what was being viewed in the 30 meter resolution Landsat 8 multispectral images.

To start gaining familiarity with surface features I examined Landsat 8 imagery for Path 172. On panchromatic Band 8 (15 m resolution) I traced anything that looked like a road or grass trail. That showed where people lived and traveled. On a Band 10, 7, 6 false color combination I marked all locations of active fires. That helped interpret those false colors as red indicating recently burned areas, with orange and yellow being older burn scars. Occasionally I checked Google Earth at fine resolution for interpretation guidance. The southern and central portions of that Path 172 have been analyzed at present, but not yet the northern portion. I did notice, however, the pattern of agricultural fields in the far north, some of which were orange in false color indicating warm and dark. There are patterns in the flat lowland (swampy?) areas that are new to me and challenging to interpret.

Eventually I realized that the short-wave infrared bands 6 and especially 7 were best for identifying pixels with fire flames. I combined all Paths within the country borders to the following scatter diagram (2-D histogram) showing the abundance of pixels at the various combinations of digital numbers (0 to 65535) of Bands 6 and 7.



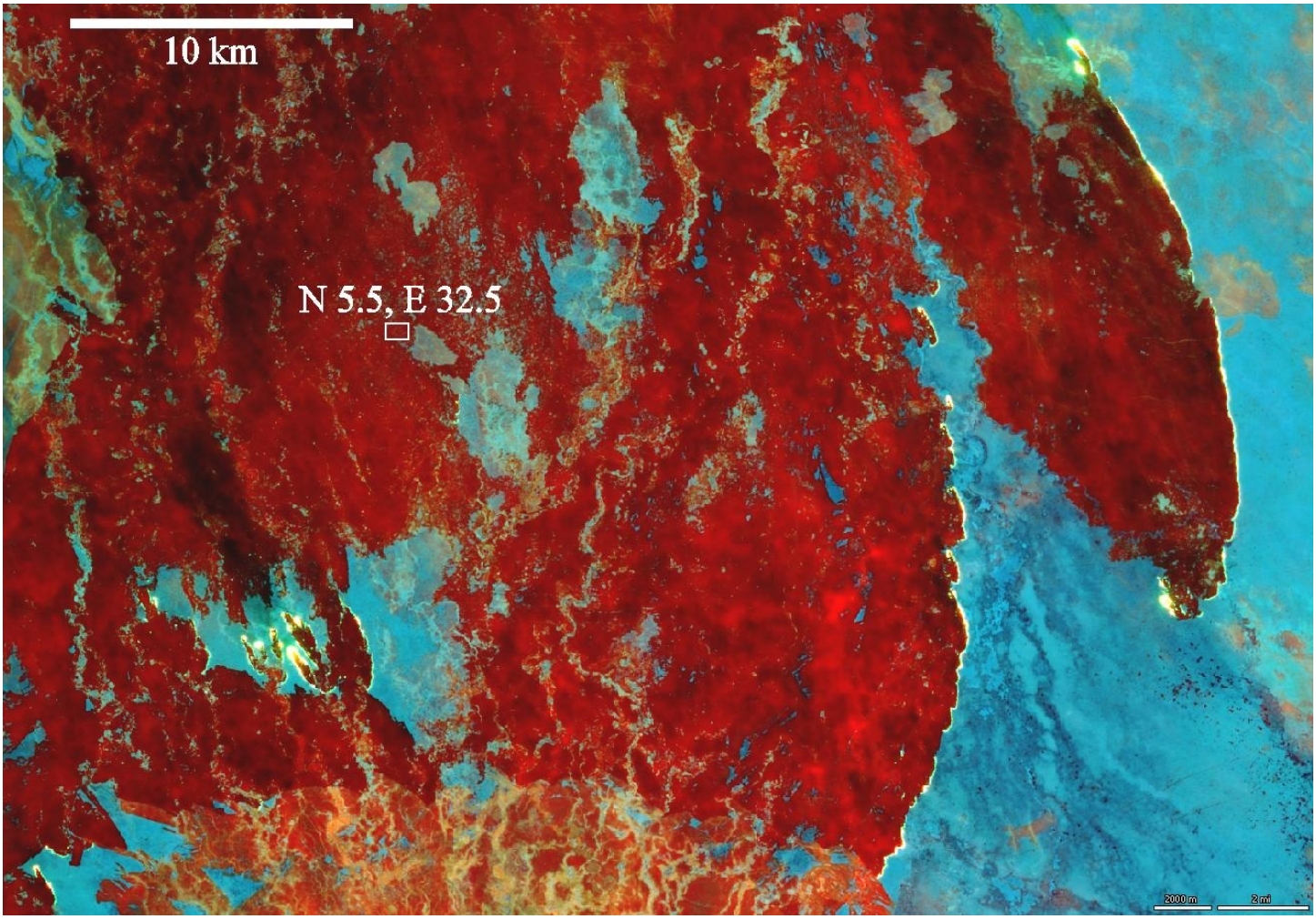
It is colorized to show great frequencies with red maximum. All pixels with band7 greater than 38,400 are fire, shown by the vertical line at the top center. In addition, all pixels to the right of the diagonal line are also fire. That algorithm was applied to all Path areas within the country boundaries.

The Paths overlap, so some areas are sampled twice but on different dates. The table below summarizes the

results with rounded numbers. The “ratio” is that between the flame area and the total area of each Path view. Flames are obviously a tiny fraction (0.000176) of the landscape, but in total the flames occupied 143.75 km^2. Correcting for the actual country area, using 631,928 km^2 and the final ratio for all areas combined, there are 111.35 km^2 of flames observed across South Sudan by Landsat 8 on those dates.

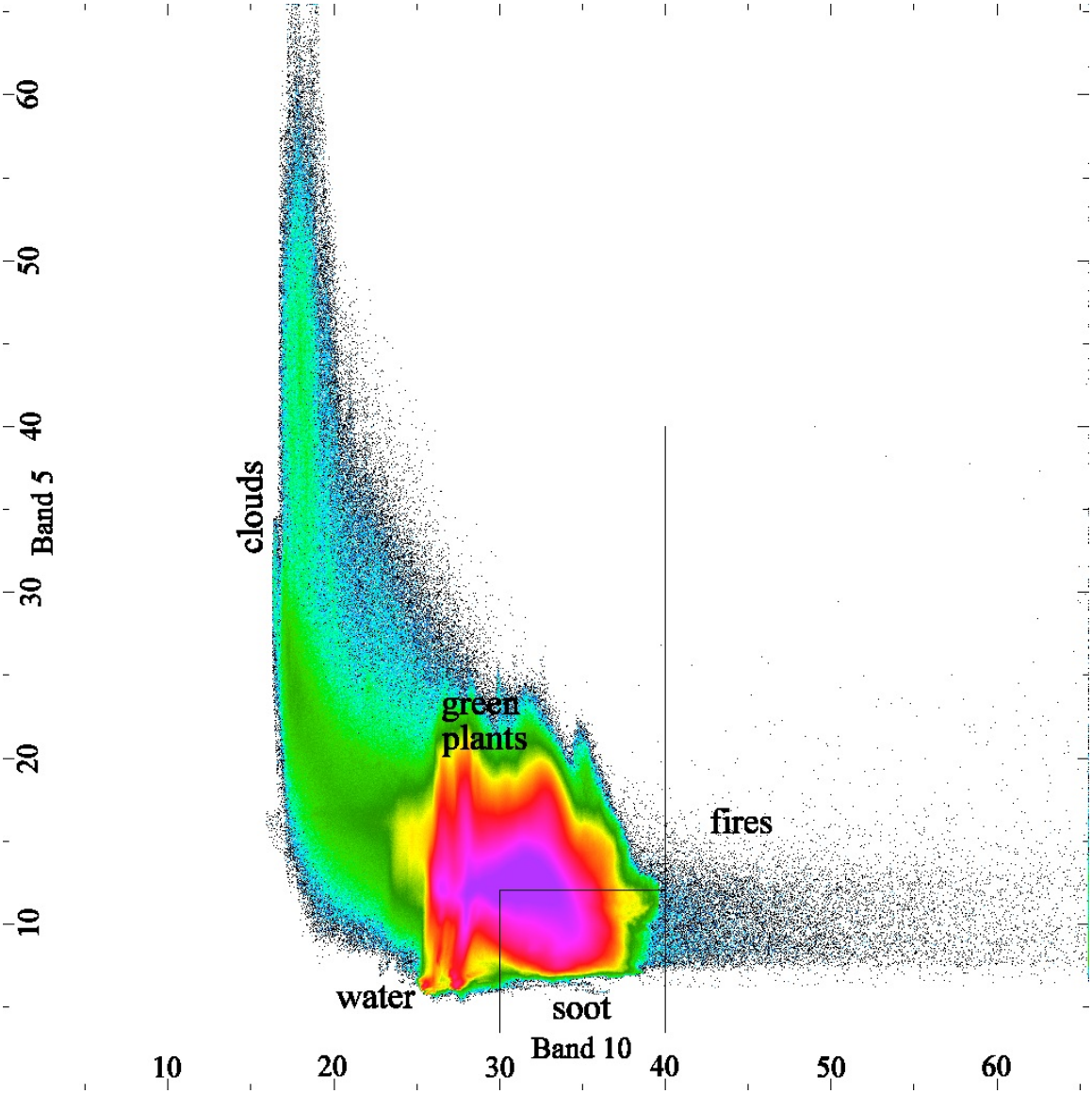
Type Path:	170	171	172	173	174	175	176	177	178		all
flames	1.14	13.89	31.34	29.40	26.00	14.70	20.79	5.13	1.37	km^2 of flames	143.75
view area	17.5	68.5	144.8	149.3	119.2	108.9	69.3	51.5	18.2	thousand km^2	747.3
ratio	0.65	2.03	2.16	1.97	2.18	1.35	3.00	1.00	0.75	$x10^{-4}$	1.76

A sample of some major fires is shown next. It is from Path 172 of 12 January 2019, displayed as Bands 10,7,6 as Red-Green-Blue. As already indicated, in this false color version red is for freshly burned areas and orange for burned earlier. Bluish is for healthy vegetation. Yellow to white are the flames, with two lines about 23 km long on the right side. The location of the Google Earth half-degree sample at N 5.5, E 32.5 of 25 March 2020 is outlined in white. A 10 km scale bar indicates the scene size.



On the next page is the Google Earth sample image from that half-degree location, about 14.5 months after the Landsat 8 image. The devastation is nearly total, with only a few small green trees surviving the fire.

Next the burned areas were examined. They are initially black after a fire but fade as wind and rain disperse the soot. Near-infrared Band5 is best for identifying green plant conditions. Small numbers in Band5 indicate something dark. That can be soot and it can be water. Healthy vegetation is bright in Band5. Temperature is best to separate soot and water, and thermal infrared Band10 does that.



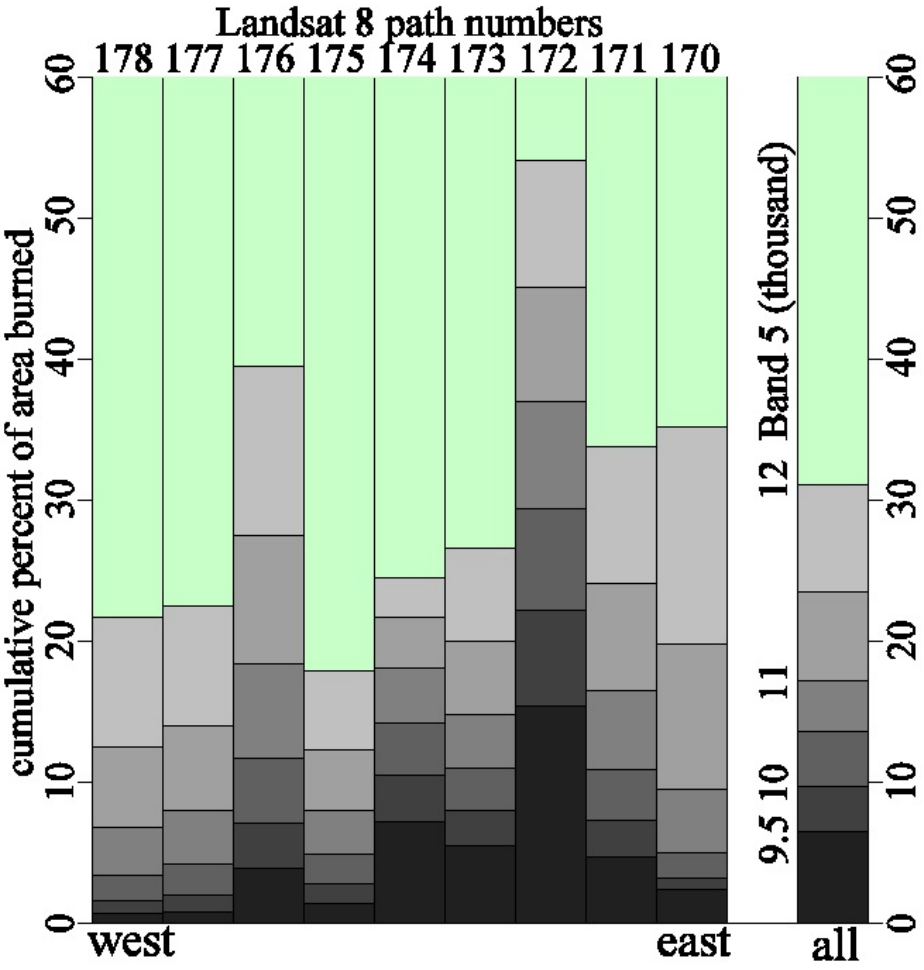
The next scatter diagram (2-D histogram) shows the relationship between the digital numbers of Band5 and Band10 for all areas within South Sudan boundaries. The axes are actually in thousands for pixel numbers (0 to 65535).

Clouds are very bright in Band5 but cold in Band10, thereby forming the left column of the distribution. Band10 is less sensitive to flames, but pixels with values greater than 40000 can be considered to be fires. Water areas are in the lower left of the red distribution, indicating cool and dark. Green plants are in the top of the reddish distribution.

Careful examination of many scenes indicated that an approximate partition can be drawn for soot. Values between 30000 and 40000 for Band10 and less than 12000 for Band5 indicate soot. Cloud shadows were usually slightly cooler in Band10. The gradient in Band5 numbers from 5000 to 12000

indicates the fading of the soot darkenings. Therefore the analysis subdivided soot by steps of 500 for Band5 values less than 12000.

The next graph displays for each Path, and all combined, the cumulative percent of area burned, according to this soot partition. The gray shadings are in steps of 500 for the Band 5 numerical values. Darkest are at the bottom for freshly burned areas. Lightest are at the top for old burn scars, for which the definitions are becoming questionable. Pale green represents unburned areas, extending beyond the top to 100 percent. Each Path has a different percentage burned. For the combined column at the right, it seems reasonable to conclude that about a quarter (25 percent) of the country of South Sudan has been recently burned.



It looks like much of the country has been burned in recent years, even in most of the supposedly protected areas. So much burning releases carbon dioxide as a greenhouse gas to contribute to global warming. There is little indication that the burning is to enhance slash-and-burn agriculture for the limited population of the country. Some burning may be to promote grasslands for cattle grazing, but cattle emit methane which also is a greenhouse gas for global warming. I have not seen any indication that trees are being harvested on large scales for timber. The soil in tropical areas usually deteriorates quickly when deprived of the usual vegetation. Wildlife habitat is destroyed by these extensive fires, likely causing endangerment to many species. It seems likely that only a proper education program for rural populations is needed to promote habitat protection and conservation of natural resources and reduce the excessive and wasteful burnings.

Additional studies can be performed with these free data sets of South Sudan. I have a generalized geologic map of the country, but the Landsat 8 and Google Earth and ASTER elevation data show more detail. The Landsat 8 panchromatic imagery is sufficient for tracing the roads and paths throughout the country, subject to verification with the finer Google Earth imagery. It is sufficient for indicating settlements of villages and urban areas. With Google Earth imagery, roof types (thatch, metal, other) and building geometry can be identified. Vegetation cover could be mapped, but the fire swaths interfere with that. Agricultural fields are easy to identify. Maybe some day I should visit South Sudan to do more ground-truth observations in addition to enjoying the wildlife

and vegetation and settlements there.

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