## Multispectral Satellite Data Preparation using MapInfo Virtual Rasters (MVR) and the MapInfo Raster Rendering Engine (MRD) – Sam Roberts August 2020

**Introduction**

In 2019 a processing capability was developed that uses MapInfo Virtual Raster (MVR) technology and the MapInfo Raster Rendering Engine (MRD) to prepare multispectral satellite data collected by the Landsat and Sentinel–2 platforms.

An MVR is an XML file that contains a description of a virtual raster. It can be loaded into MapInfo Pro in just the same way as a standard raster. The MVR will draw upon multiple raster sources and can use on-the-fly processing operations like calculator expressions. An MRD is an XML file that contains a description of a rendering algorithm. It can be loaded into MapInfo Pro in just the same way as a standard raster. When you load an MRD, the new rendering engine is invoked to render the algorithm, before it is passed to MapInfo via the raster handler. In effect, the MRD file is a back door that allows you to access this new rendering engine prior to it being fully adopted in MapInfo Pro. An MVR can also invoke the new rendering engine using an algorithm that is inside the MVR file. This provides a second mechanism to access the rendering engine and this method is used extensively by this processing operation.

**Execution**

The processing operation can be invoked by a call to the “MIR\_ExecuteProcess” API function, found in both the Raster C-API and the Raster C# API. Internally, we run an application called RasterProcessor which provides the same capability. In both cases, you need an XML file containing the processing commands. Below are two examples of these XML files.

<?xml version=**"1.0"** encoding=**"UTF-8"**?>

<RasterProcessing>

<RasterOperationList>

<SatelliteImport>

<SourceFilename>**\L7\Collection1\LE07\_L1TP\_091082\_20191230\_20200126\_01\_T1\LE07\_L1TP\_091082\_20191230\_20200126\_01\_T1\_MTL.txt**</SourceFilename>

<DestinationPath>**\L7\Collection1**</DestinationPath>

</SatelliteImport>

</RasterOperationList>

</RasterProcessing>

<?xml version=**"1.0"** encoding=**"UTF-8"**?>

<RasterProcessing>

<RasterOperationList Primary=**"True"**>

<GatherFiles Mode=**"OneByOne"**>

<TargetDir>**C:\Temp\Satellite\Sentinel**</TargetDir>

<TargetName>**MTD\_\*.xml**</TargetName>

<OpListName>**SatImportS2AB**</OpListName>

<Parallel>**False,8**</Parallel>

</GatherFiles>

</RasterOperationList>

<RasterOperationList Name=**"SatImportS2AB"**>

<SatelliteImport>

<DestinationPath>**C:\Temp\Satellite\Sentinel**</DestinationPath>

</SatelliteImport>

</RasterOperationList>

</RasterProcessing>

The first example contains a “SatelliteImport” operation. This will import a single satellite scene and, in this case, we are targeting a Landsat 7 ETM+ scene. You only need to specify the path to the scene and the output path and, in this example, both are relative to the location of the XML file. Note that for Landsat 7 we target the supplied MTL.txt file which is distributed as part of the scene package.

The second example contains a batch processing operation that can process multiple satellite scenes. The “primary” operation list is executed which runs a “GatherFiles” operation. It finds all files in the target directory, or below it, that match the target filename specification. For Sentinel-2 we target the MTD.xml file. Once a target file is acquired it is passed to a SatelliteImport operation for processing.

When you execute the operation, a number of files will be created. They will mostly be MVR files, with some MRD files and in some cases a LEG file may be output as well. You will be able to display these MVR and MRD file in MapInfo Pro. All the output files are named after the primary scene identifier and use a variety of unique suffixes.

The operation was developed to make it easier for users to import satellite multispectral scenes in all the variety of formats that they are found into a common format. That common format (MVR) does not duplicate the raster data – it simply links to it via the virtual raster technology. The MVR rasters always reference the original scene raster data. The end game is –

* to present the scene as RGB images using standard band combinations
* to provide rasters of a variety of standard band ratio expressions, which are computed on the fly
* to present QA data both visually and in a format where it can be used for processing

**Platform Support**

The operation currently supports processing of Landsat and Sentinel-2 scenes, but it could be expanded in the future to support other satellite platforms. The information below summaries the platforms, instruments, products and formats that the operation can access.

Landsat 1, 2, 3

These platforms flew from 1972 to 1983 and carried MSS and RBV instruments. We provide no support for these platforms.

Landsat 4, 5

These platforms flew from July 1982 to January 2013 and carried MSS and TM instruments. We support scenes from both platforms and instruments.

Landsat 6 (failed at launch), 7

This instrument flew from April 1999 to January 2020, although a major failure in May 2003 was never able to be resolved and all scenes since then are missing strips of data on the left and right edges of the scene. It has an ETM+ sensor which includes thermal and panchromatic bands. Up Landsat instruments to Landsat 7 have a spectral resolution of 8 bit. We provide full support.

Landsat 8, 9 (due to launch mid-2021)

Landsat 8 provides coverage from February 2013 to the present day. It uses an OLI and TIRS sensor (data from both instruments are distributed in each scene) to provide spectral, thermal and panchromatic bands in 12 bits of spectral resolution. Landsat 9 is due to launch in 2021 and uses an improved version of the Landsat 8 sensor arrays with higher spectral resolution of 14 bit. Landsat spatial resolution has improved slightly over the years and since Landsat 7 has included 30 metre spectral bands and a 15 metre panchromatic band. Thermal band resolution is lower. We support Landsat 8 but the software will have to be upgraded once Landsat 9 data becomes available.

Sentinel – 2A, Sentinel - 2B

Sentinel 2 carries an MSI instrument and the two platforms are basically identical. 2A was launched in June 2015 and 2B was launched in March 2017 and both have been operating to the present day. Although Sentinel – 2 does not include a high-resolution panchromatic band, the MSI instrument returns some bands in 10 metre resolution. We provide support for both platforms.

**Product Support**

All these platforms carry passive instruments that measure the intensity of the sunlight reflected from the surface of the Earth. These measurements are recorded as “Digital Numbers” and are often referred to as “DN”. Historically, Landsat scenes have been provided as DN and are the standard product.

There are a variety of corrections that can be made to DN to convert it to more useful standard products. Firstly, DN can be converted to “Top of Atmosphere Spectral Radiance” or to “Top of Atmosphere Reflectance”. TOA Reflectance can also be corrected for solar elevation. Thermal band DN can be corrected to “TOA Brightness Temperature”. TOA products are easy to compute from DN using simple formulas that rely on a collection of constants. These are recorded for each scene and provided in the scene metadata. The processing operation provides support for converting all Landsat DN products to TOA products on the fly.

Whilst TOA scene data is an improvement over DN data, the best data is corrected for Bottom of Atmosphere (BOA) – otherwise known as Surface Reflectance (SR) or Surface Temperature (ST) for thermal bands. This correction relies on other remote sensing platform data and is more complicated to perform. Users generally rely on the correction to be applied by the platform owners.

In addition to DN, TOA and BOA products, platform owners may also provide a variety of Science products that map certain Earth states such as Surface Water Extent, Snow Cover or Burned Extent. It may be necessary to request these products to be computed on demand for selected scenes.

**Format Support**

Landsat data is provided in multiple formats which have changed over the years. The primary formats for individual scenes are “Pre-collection”, “Collection 1” and “Collection 2”. A scene in Pre-collection format is supplied as a TIFF file containing DN values for each spectral band. It includes a MTL.TXT metadata file (the operation needs to be pointed at this file). Landsat 8 data includes a QA band but earlier platforms do not.

Collection 1 is physically almost identical. Data is generally available in three tiers – “Real Time”, “Tier 1” and “Tier 2”. Real time scenes are made available quickly after observation, but may not be fully processed. Tier 1 scenes are fully processed, high quality data. Tier 2 are fully processed, low quality data that may be affected by high cloud coverage or poor ground control point coverage.

Collection 2, which is not yet supported by our processing operation, is supposed to become available in 2020 and is designed to support Landsat 9 initially, before being extended to Landsat 8 and historical platforms. It will use a COG raster format, which is an improvement over a standard TIFF. It will also ship BOA products as standard (in addition to the DN and TOA products), which is a major step forward for consumers.

Sentinel-2 provides two products that we support – “Level-1C” and “Level-2A”. Both are superior to the current Landsat products. Level-1C provides TOA corrected reflectance bands. Level-2A provides BOA corrected reflectance bands, equivalent to Landsat Surface Reflectance. There is another Level-1B product that we do not support which provides TOA radiance bands. Note that ESA do not provide an equivalent to the Landsat DN product.

In summary, the best product currently available is Sentinel-2 Level-2A which provides BOA bands in higher resolution than Landsat 8. When Landsat 9 launches in 2021 the USGS will have a very competitive product, although the spatial resolution of Landsat 9 is lower than Sentinel-2. Whether you use the higher or lower resolution data may depend on the scale of your area of interest – Sentinel-2 coverage over an AOI will require processing 10X more data than Landsat 8/9.

In summary –

* Landsat 4+5 MSS Scene – target the \*MTL.TXT file for Pre-Collection and Collection 1.
* Landsat 4+5 TM Scene – target the \*MTL.TXT file for Pre-Collection and Collection 1.
* Landsat 7 ETM+ Scene – target the \*MTL.TXT file for Pre-Collection and Collection 1.
* Landsat 8 OLI/TIRS Scene – target the \*MTL.TXT file for Pre-Collection and Collection 1.
* Sentinel 2A+2B MIRS Scene – target the MTD\_\*.XML file for Level-1C and Level-2A.

If you have acquired an SR/BOA scene for any Landsat platform then the scene will contain an XML file with no characterising suffix. You can point the operation at this file to process these scenes.

You can combine a Landsat SR scene with the standard DN data for the same scene. In this case, point the operation at the \*MTL.TXT file and if all the data files are in the same directory, the operation will output both DN, TOA and BOA rasters.

As an alternative to downloading data from the platform owner (USGS, ESA etc.), you can also acquire satellite scenes from Amazon Web Services (AWS). Both Landsat and Sentinel-2 scenes can be found in an AWS S3 repository.

If you download a Landsat scene from AWS you will find that the TIFF files are shipped with OVR files that contain the overview pyramid. This can be advantageous as it means we do not have to produce PPRC files (our own OVR file replacement). Point the operation at the normal \*MTL.TXT file to process a scene from AWS. However, I have noticed that the OVR files have been generated for AWS are all incorrect. They blend the null value (zero) with the DN values and this pollutes the data on the edge of the scene in the pyramid. I have found it better to delete all the OVR files and generate new PPRC files.

When you run the operation, it will generate PPRC files for any rasters that do not already have them. This leads to a trap – if you have already displayed one of the rasters in MapInfo Pro then it will have a PPRC file and it will not get regenerated. However, the PPRC file will suffer from the same problem that the AWS OVR files exhibit. For this reason, I advise deleting all PPRC and OVR files before running the operation for a scene.

**Output**

The operation produces a variety of products depending on the platform, instrument and product –

1. Spectral bands combined into a multi-banded raster
2. TOA corrected spectral bands in a multi-banded raster
3. RGB algorithms based on selected spectral bands
4. RGB algorithms based on pan-sharpened selected spectral bands
5. Multi-field multi-banded rasters containing spectral band ratios and other formula
6. QA rendering algorithms
7. QA band decoded into a multi-banded raster

**Output – Landsat 8**

For example, if we process a Landsat 8 DN Product in Collection 1 format, then we get the following collection of files. For Landsat 7 the result is very similar.

\*.pprc, \*.ghx

For each spectral band TIFF file we produce a PPRC file and a GHX file. The PPRC file contains the overview pyramid and the GHX file contains the full base level statistics for that band.

\*\_DNData.mvr

The spectral bands, containing DN values, are brought together into a multi-banded MVR. The spectral bands may have different spatial resolutions, but this is not an issue for an MVR.

\*\_DNImages.mvr

A multi-field raster where each field contains an RGB rendering algorithm based on standard band combinations. The band combinations are listed below. The operation will only produce those band combinations that are valid for the platform, instrument and product. You can easily display this raster in MapInfo Pro and select which algorithm you want to see by changing the field.

Natural Color Red, Green, Blue

Natural Color With Atmospheric Removal SWIR2, NIR, Green

Natural Color With Atmospheric Removal High SWIR1, NIR, Green

False Color Blue, Green, Red

False Color (Urban) SWIR2, SWIR1, Red

False Color Infrared (Vegetation) NIR, Red, Green

False Color (Vegetation and Water) NIR, SWIR2, Coastal

Shortwave Infrared SWIR2, NIR, Red

Short-Wave Infrared Narrow SWIR2, NNIR, Red

Agriculture SWIR1, NIR, Blue

Healthy Vegetation NIR, SWIR1, Blue

Vegetation Analysis SWIR1, NIR, Red

Geology SWIR2, SWIR1, Blue

Bare Earth SWIR1, Green, Blue

Fire Scar SWIR2, NIR, Blue

Land/Water NIR, SWIR1, Red

Bathymetric Red, Green, Coastal

Atmospheric Penetration SWIR2, SWIR1, NIR

Atmospheric Penetration B" SWIR2, SWIR1, NNIR

RGB(NIR,RedE1,Red) NIR, RedE1, Red

RGB(NIR,RedE2,Red) NIR, RedE2, Red

RGB(NIR,SWIR1,SWIR2) NIR, SWIR1, SWIR2

In the list above, I use code words for each band. Not all platforms or instruments will support all bands. Here is a description of each code –

Coastal Coastal Aerosol Blue

Blue Visible Blue

Green Visible Green

Red Visible Red

Pan Panchromatic

RedE1 Vegetation Red Edge High Frequency

RedE2 Vegetation Red Edge Mid Frequency

RedE3 Vegetation Red Edge Low Frequency

NIR Near Infra-red

NNIR Narrow Near Infra-red

Water Water Vapor

Cirrus Cirrus Cloud

SWIR1 Short wave Infra-red High Frequency

SWIR2 Short wave Infra-red Low Frequency

TIRS1 Thermal Infra-red High Frequency

TIRS2 Thermal Infra-red Low Frequency

QA Pixel classification QA code

RQA Radiometric Saturation classification QA code

AQA Aerosol classification QA code

\*\_DNIndex.mvr

A multi-field multi-band raster which computes a wide variety of band ratios and other formula on the fly using virtual rasters that implement calculator expressions. The raster may contain fields for Geology, Metal, Agriculture, Soil, Fire, Vegetation, Tasselled Cap and Other. Within each field there may be many bands, each containing a ratio measure. For example, under the Vegetation field there may be a band called "NDVI" which is the "Normalized Difference Vegetation Index" and is computed with the following formula "(NIR-Red)/(NIR+Red)". There are too many formulas to list here.

\*\_PanImages.mvr

This raster is much like the DNImages raster, except that pan-sharpening is applied to each RGB combination. To support this there are two intermediate rasters called \*\_Pan.mvr and \*\_PanRGB.mvr. These are not suitable for display or use, other than as intermediate rasters for the PanImages mvr.

\*\_TOAData.mvr

This raster applies the TOA corrections to the DN data. It uses calculator expressions and acquires constants for each spectral band from the metadata file associated with the scene. Three fields are generated – containing radiance, reflectance and brightness temperature.

\*\_TRImages.mvr

This raster uses the TOA corrected reflectance data and then generates the same RGB algorithm fields as you see in the DNImages raster.

\*\_TRIndex.mvr

This raster uses the TOA corrected reflectance data and then generates the same band ratios as you see in the DNIndex raster.

\*\_PanTRImages.mvr

This raster uses the TOA corrected reflectance data and then generates the same pan-sharpened RGB algorithm fields as you see in the TRImages raster. Once again there are two intermediate files – PanTR and PanTRRGB – which are not suitable for use.

\*\_QAClass.mvr

The QA band in a Landsat 8 scene is a combination of bit values and the meaning of those bits varies according to the scene format. The operation creates a legend file, in this case called Landsat8\_C1\_QA.leg, that is used to classify the QA values and render them. This raster contains a virtual classification operation.

\*\_QAValues.mvr

In this raster, we tease out the individual channels of information in the QA band, and separate them into individual bands. Having done so, it is now easier to interpret the information in the QA band.

\*\_QARender.mrd

This rendering algorithm displays the QA band using the color information that is present in the legend file.

**Output – Sentinel-2**

If we process a Sentinel-2 scene in either Level-1C or Level-2A format, then we get a reduced set of files. Firstly, the raster data is in JP2 format so no PPRC files are required. There is no need to perform TOA corrections as the data is already corrected. There is no opportunity for pan-sharpening (as Sentinel-2 does not include a high-resolution panchromatic band) so no pan-sharpened image algorithms are generated. Finally, we do not currently process the QA bands in Sentinel-2 data. We only generate three files –

\*\_Data.mvr – The spectral bands brought together into a multi-banded MVR.

\*\_Images.mvr - A multi-field raster where each field contains an RGB rendering algorithm based on standard band combinations.

\*\_Index.mvr - A multi-field multi-band raster which computes a wide variety of band ratios and other formula on the fly using virtual rasters that implement calculator expressions.

**Output – Landsat 4 & 5**

For Landsat 4 and 5 MSS and TM instruments we get a similar result to Landsat 7 and 8. However, there is no panchromatic band so no pan-sharpened imagery is produced. Also, there is a smaller set of spectral bands so the number of valid RGB combinations and band ratio combinations is reduced. We do process the QA band.

**Output – Landsat BOA Surface Reflectance**

In this case the output is similar to Sentinal-2.

\*\_SRData.mvr – The spectral bands brought together into a multi-banded MVR.

\*\_SRImages.mvr - A multi-field raster where each field contains an RGB rendering algorithm based on standard band combinations.

\*\_SRIndex.mvr - A multi-field multi-band raster which computes a wide variety of band ratios and other formula on the fly using virtual rasters that implement calculator expressions.

\*\_SRScaled.mvr – The spectral bands brought together into a multi-banded MVR with a variety of scaling operations.

**Output – Landsat combined DN and SR**

In this case we produce all the files you would normally get for a DN Landsat scene, as well as all the files you would expect for a BOA Landsat SR scene, plus we apply pan-sharpening to the SR data, drawing the panchromatic band from the DN data.

**Issues**

1. Sentinel-2 QA bands are not processed.
2. Landsat 9 Collection 2 data format is not yet supported.
3. A mechanism to clean out old PPRC and GHX files prior to executing the operation could be useful.
4. The use of multi-field MVR files for presenting rendered scenes in MapInfo Pro is problematic because the Advanced raster handler interferes and applies a color stretch to the imagery by default. This can be turned off, but as soon as you change the field via the ribbon the settings will be lost. An alternative approach using MRD files would avoid this issue as the Advanced raster handler does not automatically stretch MRD algorithm imagery.
5. There is plenty of scope to improve the set of band ratios and formulas and to improve the communication of the formulas to users. Currently it is a bit of a black box.