PROCESSING AND QUALITATIVE VISUALIZATION IN PSEUDO-TRUE COLOURS OF LONG-TERM SERIES OF SATELLITE DATA

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ABSTRACT

Free access to moderate resolution remote sensing data enable worldwide users for their studies of many key geophysical parameters of the Earth's system, solving various tasks on regular monitoring of natural phenomena, including tasks on ecological space monitoring. This requires multilevel processing of satellite data. The processing results are given for the Aral Sea. This endorheic salt lake is located in Central Asia on the border of Kazakhstan and Uzbekistan. Aral was chosen as an example not by chance as because before shallowing, it was the fourth-largest lake in the world. During the process of drying, the lake was divided into three parts. Currently, the eastern part of the lake has completely disappeared. To the Aral Sea is happening a real ecological disaster. A long-term series of satellite data are needed to monitor the dynamics of changes.

The active operation of remote sensing satellites usually exceeds their estimated lifetime. For example, spacecrafts "Terra" and "Aqua", launched in 1999 and 2002, respectively, have an estimated lifetime of sensor MODIS as 6 years, but they are still used in the NASA EOS program aimed at Earth exploration. With the aging sensors has been a degradation of its optics equipment which affects the quality of the data in some channels. It limits the simple creation of a color image in TRUE colors by put the bands spectral range of visible radiation to corresponding layers RGB-composite. The article describes the technology of making quality images by digital operations with MODIS channels. It eliminates such a problem as "banding" of the image and creates new synthesized bands. The results of processing are demonstrated using annual Terra/MODIS data for the autumn period from 2000 to 2019.

Besides, taking into account that a water body has been chosen as the object of monitoring, the article presents the options of water surface detection based on spectral indices - indices calculated in mathematical operations with different spectral ranges (channels) of remote sensing data related to certain parameters. Thematic processing in Geomatica software is shown on Landsat-8 images: the sample profile of index image is demonstrated. Taking into account that the survey area exceeds the size of the standard Landsat scene, a mosaic image was made for complete coverage of the region.

In 2021 a partnership between NASA and the U.S. Geological Survey was scheduled to launch the next spacecraft of Landsat mission which started in 1972. Thus, the repeat images will create conditions for studying the dynamics of changes in the objects under research.

Keywords: *Aral Sea, space images, Landsat, MODIS, monitoring*

INTRODUCTION

The Aral Sea is a lake in Central Asia on the border of Kazakhstan and Uzbekistan (its northern part is in Kazakhstan). The lake is located on Turan plain at the eastern Ustyurt plateau. Until 1960, the area of Aral water surface was 66.1 thousand km^2, length – 428 km, width – 2,354 km, basin area – 690 thousand km^2, water volume – 1,075 km^3 [1].

The water of the Aral Sea basin is formed mainly by large rivers – Amudarya and Syrdarya, that originate from Tajikistan and Kyrgyzstan.

Water use in Central Asia facilitated the increase of irrecoverable water intake, including from rivers feeding Aral. Their estuaries lost their water regulating capacity which affected the sea level. Precipitation in the form of rain and snow give the Aral Sea much less water than is lost while evaporating from its surface. As a result, Aral water volume reduces, and the salinity degree increases. With the water level falling, the groundwater level also reduced in Aral which accelerated the process of the region desertification. Cropped out sea bottom is covered with salts that are spread by the wind throughout the basin territory and adjacent areas.

A long-term series of satellite data are needed to monitor the dynamics of changes.

METHODS AND METHODOLOGY

Monitoring of the Aral Sea shallowing was performed with the use of archive images with moderate spatial resolution: Terra/MODIS, refining of subject information – based on data of Landsat/OLI [2], [3].

MODIS (Moderate Resolution Imaging Spectroradiometer) is one of key tools onboard of American satellites Terra and Aqua. 36 MODIS spectral zones cover the range with wavelength from 0.4 to 14.4 µm. Observations in red and infrared electromagnetic wavelength ranges are done with a resolution of 250 m, in five zones of visible and near infrared range with a resolution of 500 m, and others – 1 km. Data is freely available.

Landsat is the most long-lasting project studying the planet Earth with the help of satellite images. The first satellite of Landsat mission was launched in 1972, currently, Landsat-7 and Landsat-8 operate on orbit. Surveys of the earth surface are performed in modes: VNIR (Visible and Near Infrared), SWIR (Shortwave Infrared), PAN (panchromatic) and TIR (thermal). Landsat multispectral data spatial resolution is 30 m, in the panchromatic channel – 15 m. Starting from 2009, all satellite images of Landsat program are freely available.

The active operation of remote sensing satellites usually exceeds their estimated lifetime. For example, spacecrafts “Terra” and “Aqua”, launched in 1999 and 2002, respectively, have an estimated lifetime of sensor MODIS as 6 years, but they are still used in the NASA EOS program aimed at Earth exploration [4]. With the aging sensors has been a degradation of its optics equipment which affects the quality of the data in some channels.

Another example – functioning spacecrafts Landsat-7 and Landsat-8 were placed in orbit in 1999 and 2013 respectively, their design life according to documentation was 7 and 5 years. In 2003, there was a failure in the operation device ETM+ (Enhanced Thematic Mapper Plus) of Landsat-7. Such failure was caused by the scan line corrector. The observations are continued but in the mode of SLC-off scan line corrector turned off.

Despite sensors aging, the processing of long-term sequence of single-type satellite data requires also their quality visualization. Figure 1 shows fragments of Terra/MODIS space images for the autumn period from 2000 to 2019, illustrating changes of borders of the Aral Sea for 20 years, in the composition center – state-of-the-art of Aral by data for 2019. By Figure 1, it is possible to state that the eastern part of Aral “disappeared” for the first time in 2014, the situation repeated in 2019. The stability of the situation with Small Aral is conditioned by 17 km Kokaral dam built in 2003-2005 from the Kokaral peninsula to Syrdarya estuary. The dam has a flow-control valve to regulate the reservoir level [5].

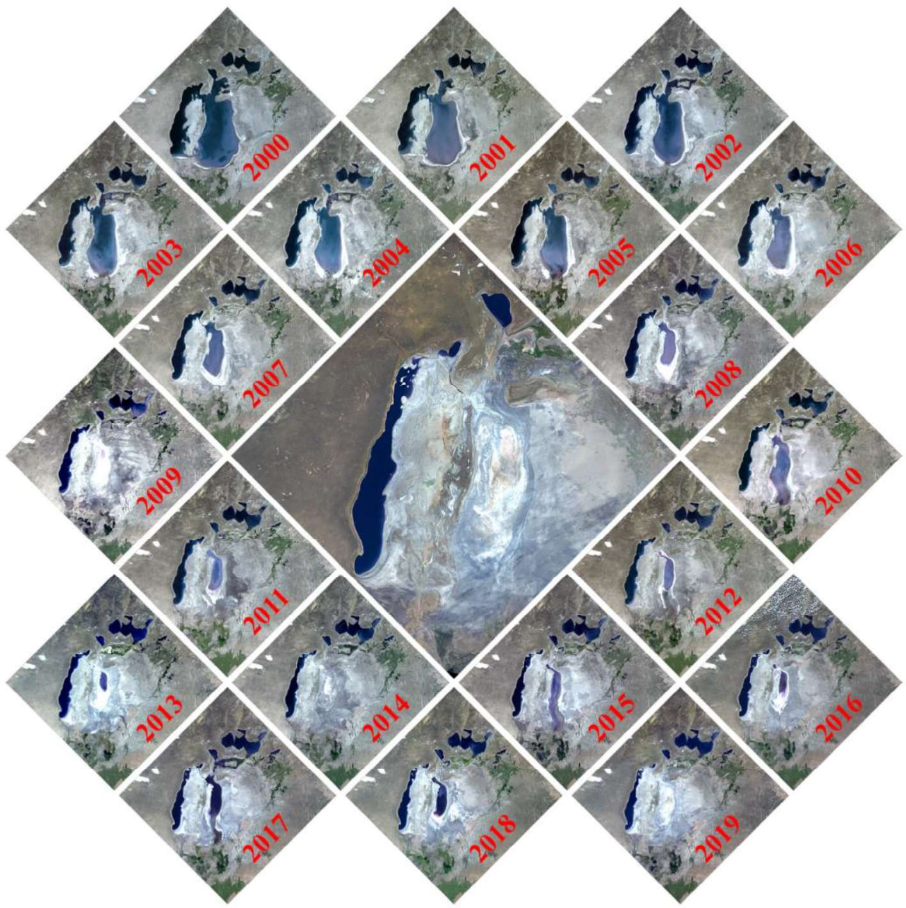


Figure 1 – Aral Sea shallowing dynamics

To obtain such a composition, the following actions were performed.

Terra/MODIS baseline data characterized by cloudless nadir location of the area under study, downloaded in the volume of 6.02 Gb in “raw” format PDS (MOD00F by EOS range of products), scene identifiers are given in Table 1.

Table 1 – List of TERRA/MODIS Identifiers

№	Identifier	Date	Time UTC
	MOD00F.A2000252.0710.20062340336.001.PDS	08.09.2000	07:10
2.	MOD00F.A2001256.0650.20062930852.001.PDS	01.09.2001	06:50
3.	MOD00F.A2002250.0650.20070080507.001.PDS	07.09.2002	06:50
4.	MOD00F.A2003249.0715.20063580602.001.PDS	03.09.2003	07:15
5.	MOD00F.A2004268.0715.20070262232.001.PDS	24.09.2004	07:15
6.	MOD00F.A2005261.0720.20062270027.001.PDS	18.09.2005	07:20
7.	MOD00F.A2006245.0650.20062461222.001.PDS	02.09.2006	06:50
8.	MOD00F.A2007248.0650.20072480720.001.PDS	05.09.2007	06:50
9.	MOD00F.A2008247.0715.20082470837.001.PDS	03.09.2008	07:15
10.	MOD00F.A2009265.0715.20092650945.001.PDS	22.09.2009	07:15
11.	MOD00F.A2010247.0655.20102470705.001.PDS	04.09.2010	06:55
12.	MOD00F.A2011246.0720.20112460709.001.PDS	03.09.2011	07:20
13.	MOD00F.A2012256.0725.20122560718.001.PDS	12.09.2012	07:25
14.	MOD00F.A2013289.0645.20132890707.001.PDS	13.10.2013	06:45
15.	MOD00F.A2014247.0715.20142470712.001.PDS	04.09.2014	07:15
16.	MOD00F.A2015266.0715.20152661009.001.PDS	23.09.2015	07:15
17.	MOD00F.A2016248.0655.20162480654.001.PDS	04.09.2016	06:55
18.	MOD00F.A2017250.0655.20172500655.001.PDS	07.09.2017	06:55
19.	MOD00F.A2018246.0650.20182460721.001.PDS	03.09.2018	06:50
20.	MOD00F.A2019263.0700.20192630653.001.PDS	20.09.2019	07:00

Files of Level 0 were converted into standardized within the frameworks of EOS products of Level1A and 1B. Processing included operations of data reformatting, its gridding and calibration.

At the initial stage, files of Level 0 were unpacked into data of Level 1A of HDF format (MOD01 by EOS range). MOD01 includes detectors' data array, and also service onboard information and metadata added to file during processing. MODIS Level1A data file gridding was carried out as the result of filling in fields of Level1A file describing the geographical position. Thus, geolocation file was formed (MOD03 product by EOS range) with arrays of latitude and longitude, survey geometrical parameters such as scan angles, Sun position and some other parameters.

Input data for MODIS calibration is data of Level 1A and geolocation (i.e. MOD01 and MOD03 files simultaneously). As a result of calibration process, standard product was created (MOD02 by EOS range) in HDF format. Each type of output files has its own standard identifier in accordance with channels special resolution: MOD02QKM (QKM/quarter kilometer), MOD02HKM (HKM/half kilometer), MOD021KM (1KM/1 kilometer). To create pseudo-true colours, files MOD02QKM and MOD02HKM were used (table 2).

Table 2 – MODIS spectral bands

MOD02	Spectral channel	Band width (mkm)	Spatial resolution (m)
MOD02QKM	channel 1 - Red	0.620-0.670	250
MOD02KM	channel 2 - Near Infrared, NIR	0.841-0.876	250
MOD02HKM	channel 3 - Blue	0.459-0.479	500
MOD02HKM	channel 4 - Green	0.545-0.565	500

A color image in pseudo-true colors is usually created by substitution channels with respective spectral range into RGB-composite. Pursuant to Table 2, for MODIS data such a composite looks like a combination of channels 1-4-3. And the resulting special resolution is contributed by two channels with resolution of 500 m, and only one channel with resolution of 250 m. Consequently, the resulting image will have resolution of 500 m. Taking into account that on later images, with regard to survey instruments ageing factor, there appeared interferences on individual channels, this is reflected by strips on images. This problem and an option for its solving is illustrated on figure 2.

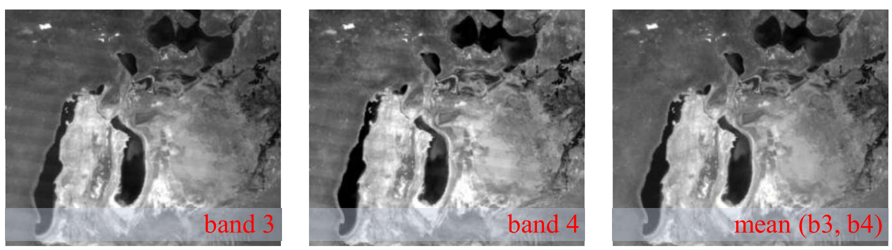


Figure 2 – View of Green and Blue MODIS channel

To achieve quality image, spectral conversion of digital data is necessary; formulas for new data synthesizing are given in Table 3. A new synthesized image nevertheless can be successfully presented with 250 m resolution since major part of baseline data in this case has resolution of 250 m.

Table 3 – RGB-composite options

R-G-B	True Colours	Pseudo-True Colours
RED	Band1	Band1
GREEN	Band4	(band2+3*SyntGreen)/4
BLUE	Band3	-0.1*band2+0.01*band1+0.7*band3+band42 as SyntGreen

RESULTS

Figure 3 presents resulting images of both options.

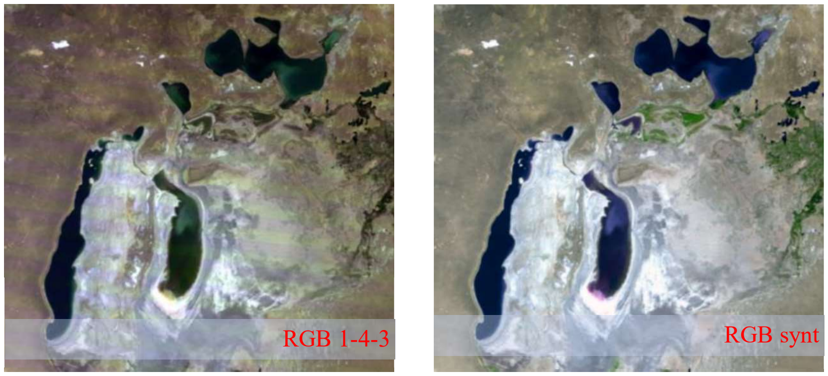


Figure 3 – Resulting images of both options

Scientists are exploring the state, trends and future of water resources development in the Central Asia [6]. Aral experiences water table level and area fluctuations. According to remote sensing data for 1975 – 2013, Aral water table area reduced by 82% [7].

Water table area is calculated as the result of subject index processing of space images. Spectral satellite information allows calculation of the following

- - vegetation index (formula 1) characterizing peculiarities of vegetation cover based on the knowledge that the most expressed peculiarity of plants range is the minimum in red spectral range and maximum in infrared

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

- - water index (formula 2) based on the knowledge that the most expressed feature of water range is minimum in infrared range and maximum in green range.

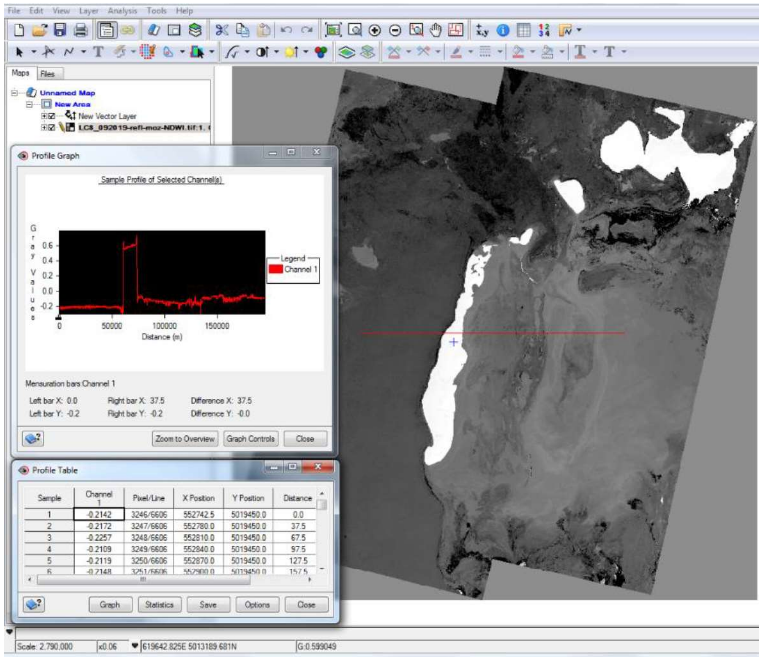
$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \quad (2)$$

Both indexes give identical results, unambiguously allowing finding a water body. Figure 4 demonstrate a profile of index images. Subject processing performed with Geomatica software.

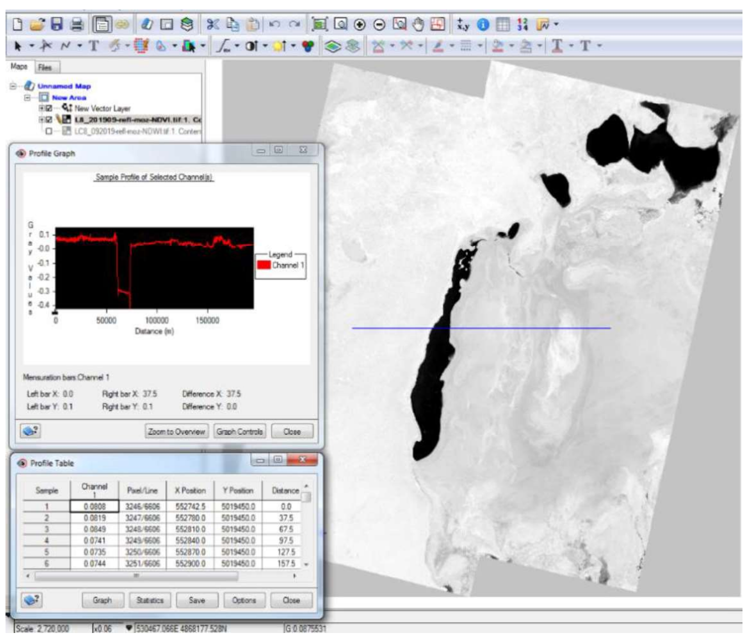
Taking into account that the study area exceeds the size of Landsat standard scene, their mosaic was made for full coverage of the Aral region, identifiers of Landsat-8 scenes used for this example are given in Table 4.

Table 4 – List of Landsat-8 identifiers

Date	Path	Row	Identifier
12.09.2019	161	28	LC08_L1TP_161028_20190912_20190917_01_T1.tar
12.09.2019	161	29	LC08_L1TP_161029_20190912_20190917_01_T1.tar
19.09.2019	162	28	LC08_L1TP_162028_20190919_20190926_01_T1.tar
19.09.2019	162	29	LC08_L1TP_162029_20190919_20190926_01_T1.tar



a)



b)

Figure 4 – Spectral index for Landsat-8 19.09.2019, 12.09.2019: a) NDWI, b) NDVI

CONCLUSION

Described technology permit to get quality images by digital operations with MODIS channels. It eliminate a “banding” problem of the image as a result of create new synthesized bands. Result – the qualitative visualization in pseudo-true colours of long-term series of satellite data.

Water detection performed on opposite spectral indices NDWI and NDVI. These numerical indicators derived from optical satellite images as mathematical operations with spectral ranges of remote sensing data. Thematic processing completed in Geomatica software.

Thus, thematic maps built on the basis of satellite images allow tracking the process of the Aral Sea shallowing – present-day ecological disaster. The repeat images will create conditions for studying the dynamics of changes in the objects under research.

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