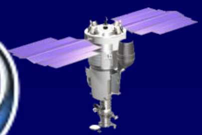


The Russian Ministry of Education and Science
Russian Academy of Science

State scientific Institution "Institute for Scientific Research of Aerospace Monitoring "AEROCOSMOS"

Image quality evaluation for resampling methods based on spatial spectrum extrapolation

speaker Vladimir Ignatiev,
A.B. Murynin, A.N. Trekin, I.A. Matveev
(ISR "AEROCOSMOS“, CC RAS)

105064, Russia, Moscow,
Gorokhovsky lane, 4
phone: +7(495)-632-16-54,
fax: +7(495)- 632-11-78
www.aerocosmos.info

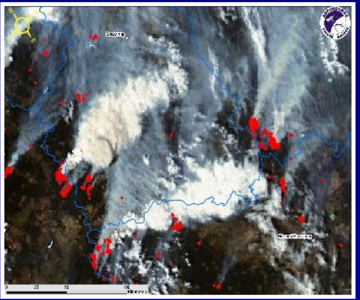
MAJOR APPLICATIONS FOR IMAGE QUALITY EVALUATION AS A TOOL OF DIGITAL IMAGE PROCESSING:

1) analysis and synthesis of the brightness fields on the input of the Earth remote sensing devices;
2) eliminating noise;
3) improving the spatial resolution of the image;
4) co-registration images of the same scene;
5) pattern recognition.

REMOTE SENSING DATA IN DIFFERENT SPHERES

- Science and economy of the developed countries
- Space data are useful for:

- defense and national security;
- environmental protection;
- prevention and elimination of consequences of natural disasters and technological accidents;
- study and management of natural resources;
- Meteorology and Climatology;
- Forestry and agriculture;
- urban development, transport and energy problems;
- Earth Science investigations;
- creating of maps, inventories, GIS products and so on.



GENERAL CHARACTERISTICS OF SPACE IMAGES

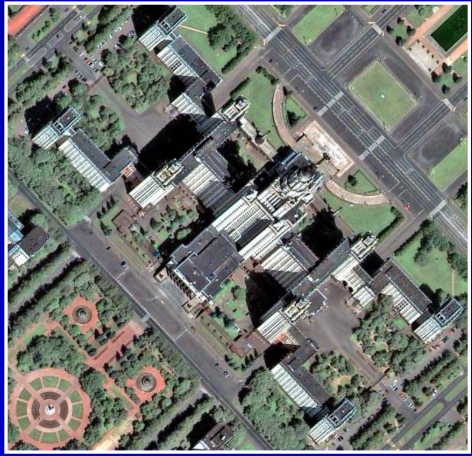
<u>Sensor type</u>

- **optical images: panchromatic, multispectral, hyperspectral;**
- **radar images.**

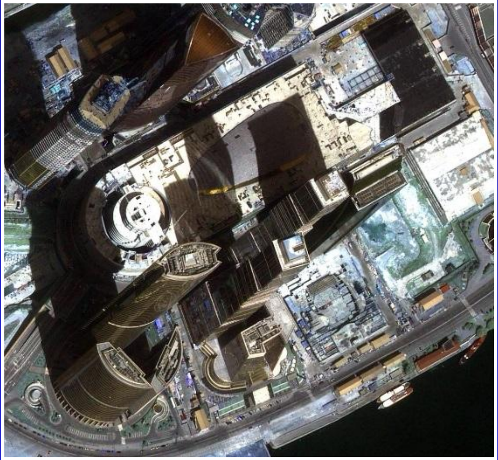
<u>Spatial resolution</u>

- **high-level (0,4 - 7,0 m)**
- **middle-level (7 - 50 m)**
- **low-level (50 - 1100 m)**

Images of ultra-high and high-resolutions



Resurs-P (Ресурс-П): 3-4 m (Lomonosov Moscow State University)

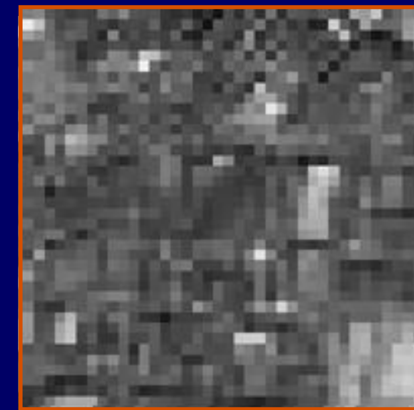


WorldView-2: 1,8-2,4 m (Moscow International Business Center)

REMOTE SENSING IMAGES SPATIAL RESOLUTION

5 meters

10 meters



20 meters

high-level resolution group

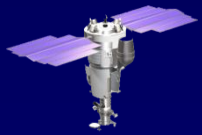
middle-level resolution group

jump to other resolution group

Existing methods of increasing resolution for aerospace images by number of used input and output images

All groups of methods:

- SISO – single input, single output;
- MISO – multiple input, single output;
- MIMO – multiple input, multiple output.



Existing methods of increasing spatial resolution of images by the way of recovery missing information

1. Regularization methods to improve the image resolution (SISO):

- Tikhonov regularization;

- adaptive regularization and adaptive selection of the oversampling regions.

2. Methods based on processing of image sequences using different types of filtration (MISO):

- linear smoothing;

- median;

- weighted median;

- adaptive;

- Gauss filtering.

3. Methods for increasing the resolution of a series of satellite images (MIMO):

- superresolution in one axis using two images;

- superresolution in two axes;

- superresolution method of subpixel scanning.

Existing methods of increasing spatial resolution of images by the way of recovery missing information

4. Methods for increasing the resolution of the image based on the use of a priori information about the objects (SISO/MISO).

5. Methods for fusion of multispectral images (pansharpening) based on (MISO):

- component replacement;
- relative spectral contribution;
- high frequency structures;
- using the statistical characteristics of the image.

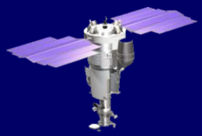
6. Methods for increasing the resolution multispectral image synthesis based on the information in the spectral channels - using a combination of the above methods.

Developed methods for increasing spatial resolution aerospace images

1. The method based on the use of reference images of the same surface areas as in the enhancement image, but with a higher spatial resolution.

2. The method based on the construction of help image.

The methods are based on a synthesis of two-dimensional stochastic fields



Needs of satellite imagery

1. Increasing the density of sensors by reducing the size of the sensor

- incident light flux is reduced;
- reducing the size of optical systems;
- increasing the noise level in the image;

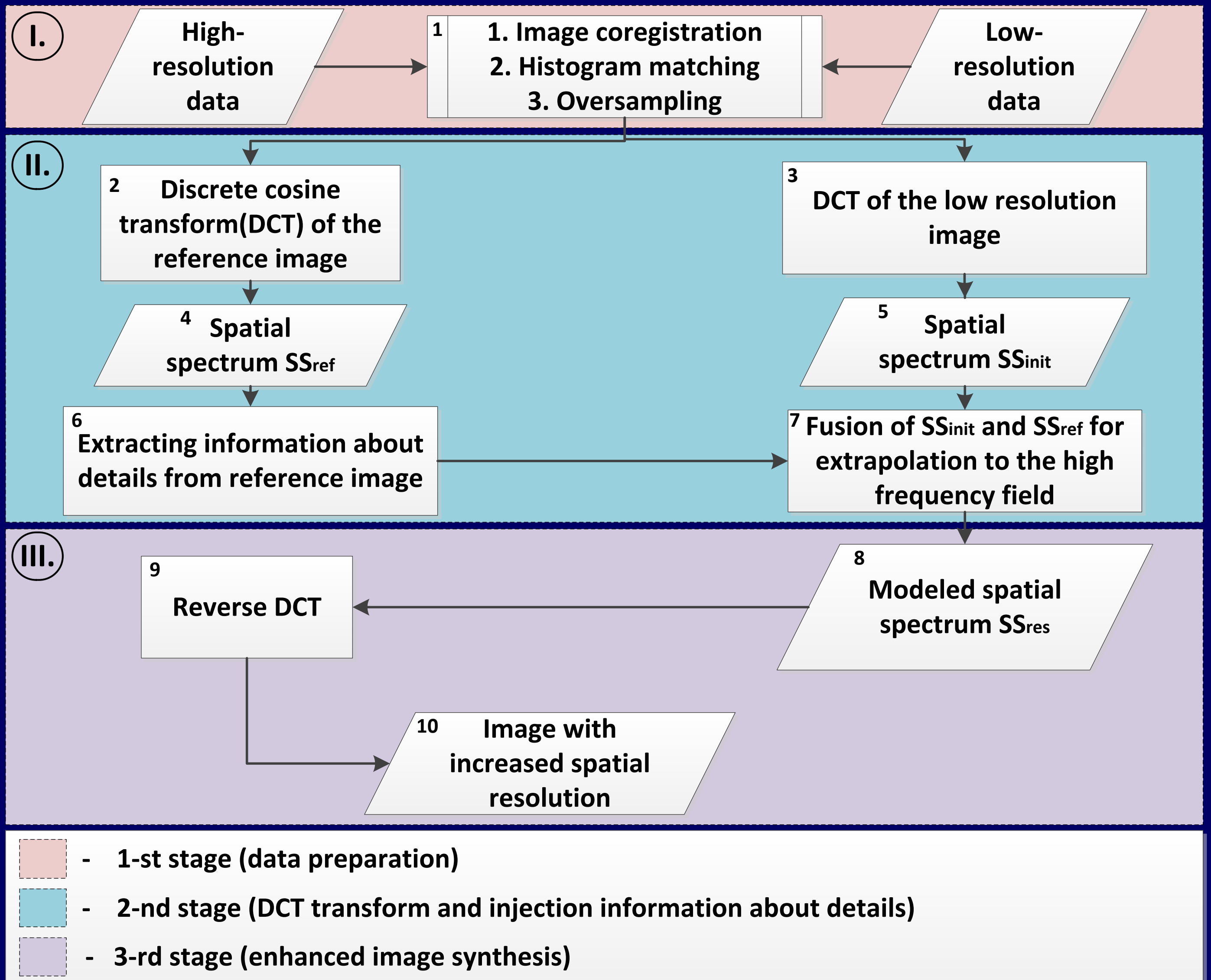
Development of new effective methods for post-processing images on the Earth.

Resampling procedure

Etalon

GOAL: study on the selection of a numerical measure of image similarity (difference) in the quality assessment problem for the resampling methods

Fusion method using reference images and extrapolation of the spatial spectrum (method M1)



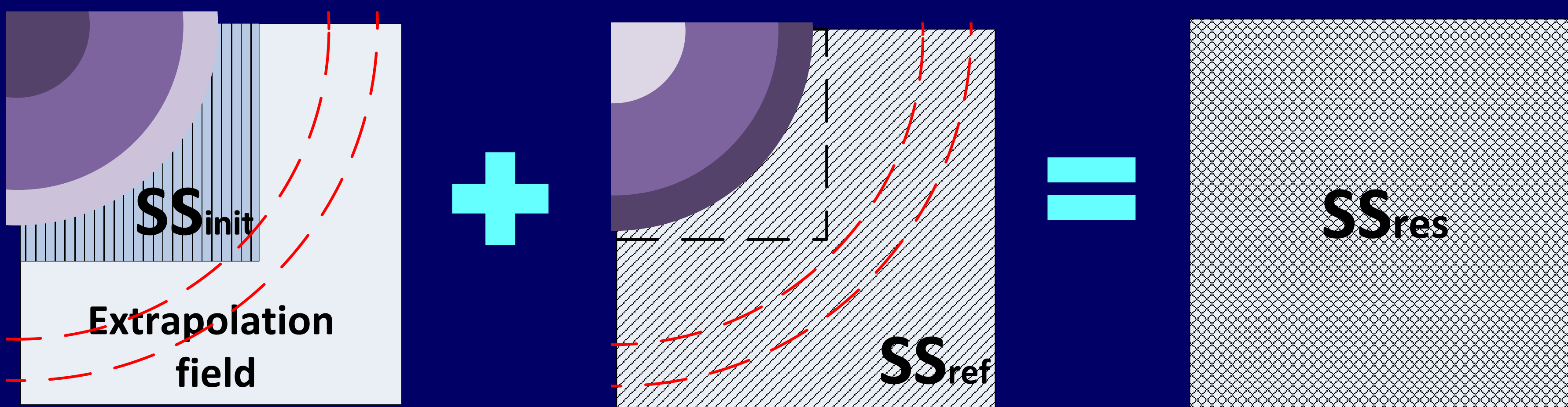
Method M1. Fusion procedure

$$SS_{res}(m,n) = G(m,n)\,SS_{init}(m,n) + \beta\big(1 - G(m,n)\big)\,SS_{ref}(m,n)$$

β - "sharpness" parameter of objects' boundaries on image

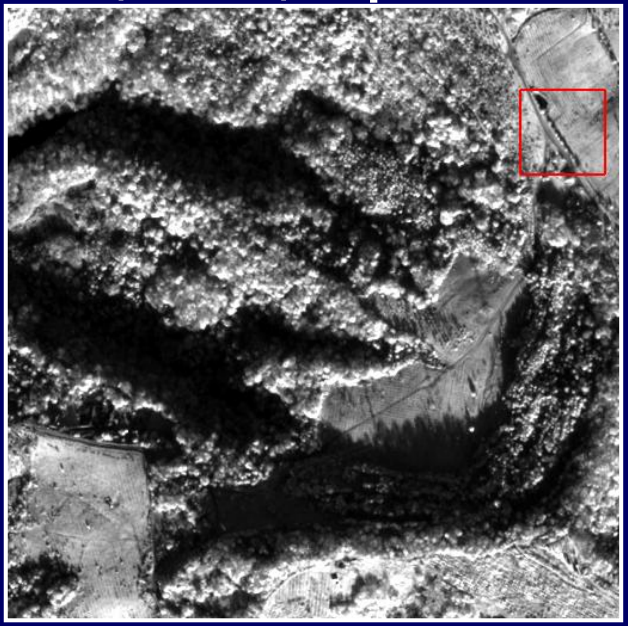
$G(m,n)$ - a weight function close to unity for small values $m = 1, \dots, M$ and $n = 1, \dots, N$, it decreases for large values

$$G(m,n) = exp\left(-\frac{1}{2\sigma^2}\left[\left(\frac{m}{M}\right)^2 + \left(\frac{n}{N}\right)^2\right]\right)$$, M,N – sizes of the resulted image.



Results of upscaling with M1 method

GeoEye-1
0,78 – 0,92 µm



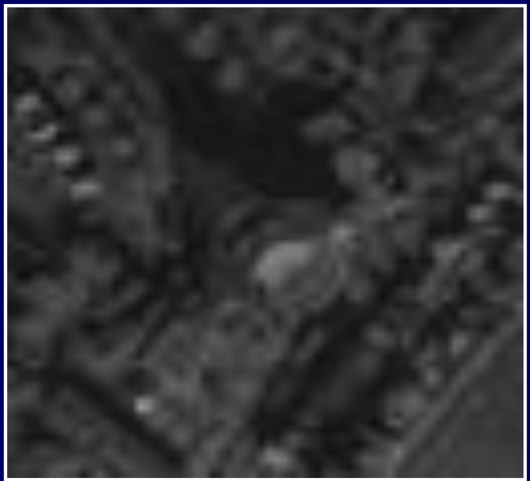
Initial fragment

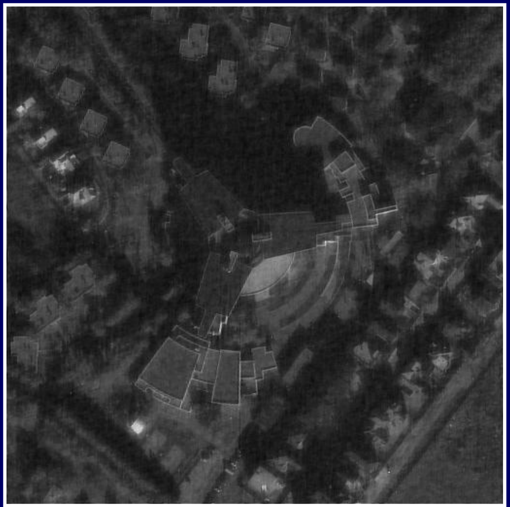
Etalon

4-times upscaling with M1

Results of upscaling with M1 method

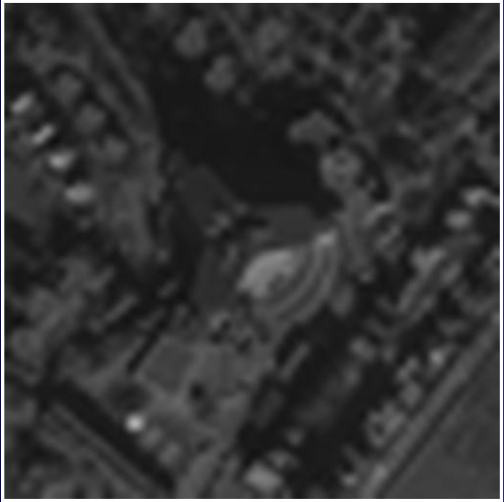
Red Channel



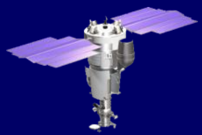


8-times upscaling with M1 method

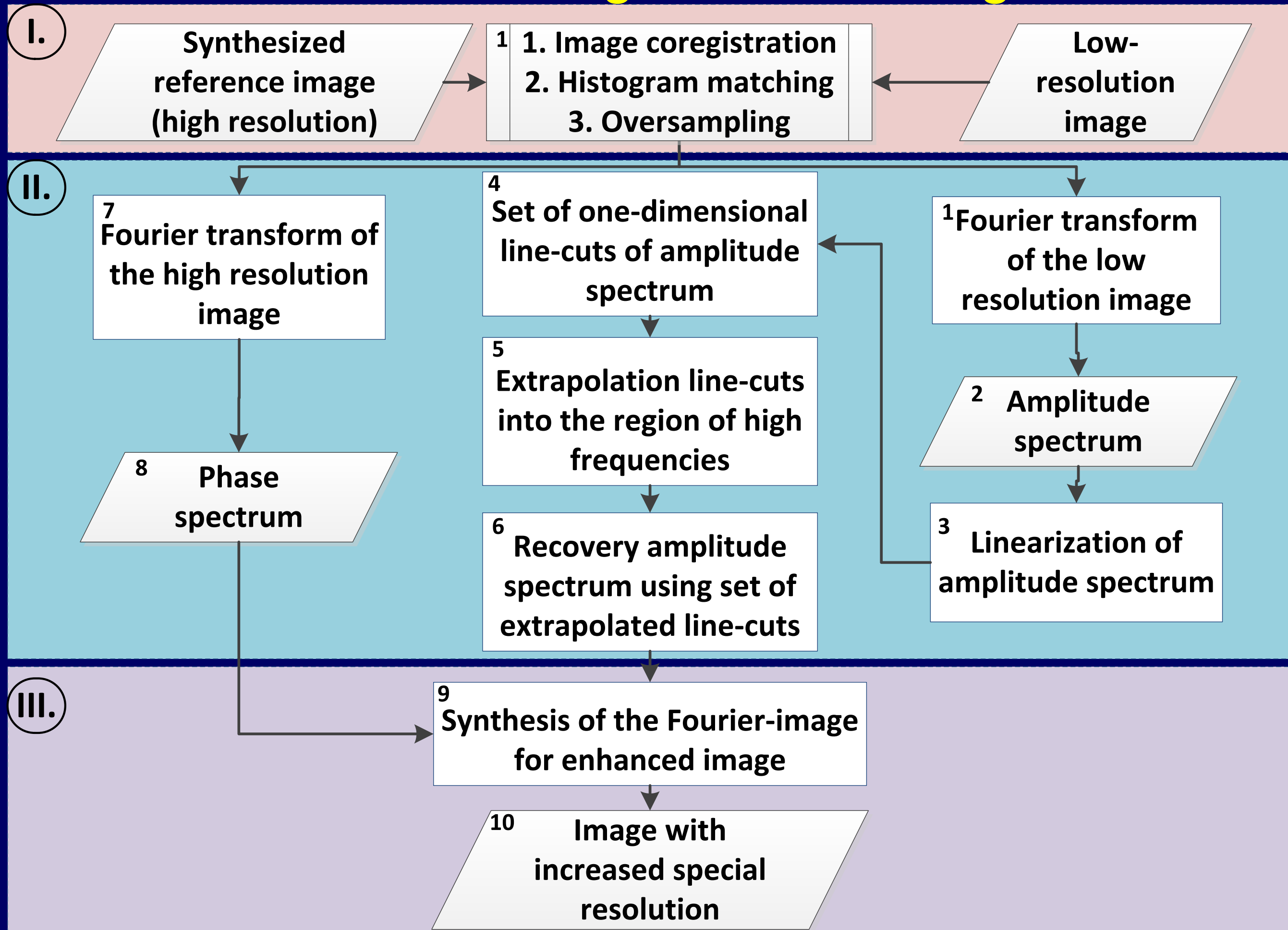
Lanczos filter



Etalon



Method of increasing spatial resolution of airspace image without using reference image



- 1-st stage (data preparation)
- 2-nd stage (amplitude spectrum modelling and injection information about details)
- 3-rd stage (enhanced image synthesis)

Results of upscaling with M2 method

Initial fragment

Etalon

2-times upscaling M2

4-times upscaling M2

Image quality evaluation problem statement

$$f:(I_{res}, I_{et}) \longrightarrow a, a \in \mathbb{R}$$

f - function depends on a metrics type;

I_{res} - resulted image with increased spatial resolution, depends on the set of parameters $(\alpha_1, ..., \alpha_K)$;

I_{et} - etalon image.

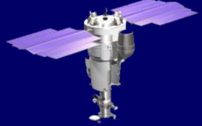
Quality evaluation stages

I-st stage:

- set of metrics’ candidates;
- set of well-known upsampling methods/algorithms;
- experiments: approved set of metrics’ candidates for different re resolution increasing scales.

II-nd stage:

- set of optimization parameters;
- set of suggested upsampling methods/algorithms;
- experiments: optimal parameters of upscaling methods and appropriate metrics



I-st stage. Set of candidate metrics

1. MSE group: RMSE, PSNR, ERGAS, MAE, NCD

$$MSE(x,y) = \frac{1}{NM}\sum_{m=1}^{M}\sum_{n=1}^{N}|x(m,n) - y(m,n)|^2$$

2. Structural similarity index

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

3. Complex-wavelet structural similarity index

$$cwSSIM(x,y) = \frac{2\left|\sum_{j=1}^{J} c_{x,j}\, c_{y,j}^{*} + K\right|}{\sum_{j=1}^{J} c_{x,j}^2 + \sum_{j=1}^{J} c_{y,j}^2 + K}$$

4. Normalized correlation coefficient

$$CC_{norm}(x,y) = \frac{\sum_{m,n}(x(m,n) - \mu_x)(y(m,n) - \mu_y)}{\sqrt{\sum_{m,n}(x(m,n) - \mu_x)^2 \sum_{m,n}(y(m,n) - \mu_y)^2}}$$

I-st stage. Comparing different metrics with using well-known upscaling methods

2-times upscaling

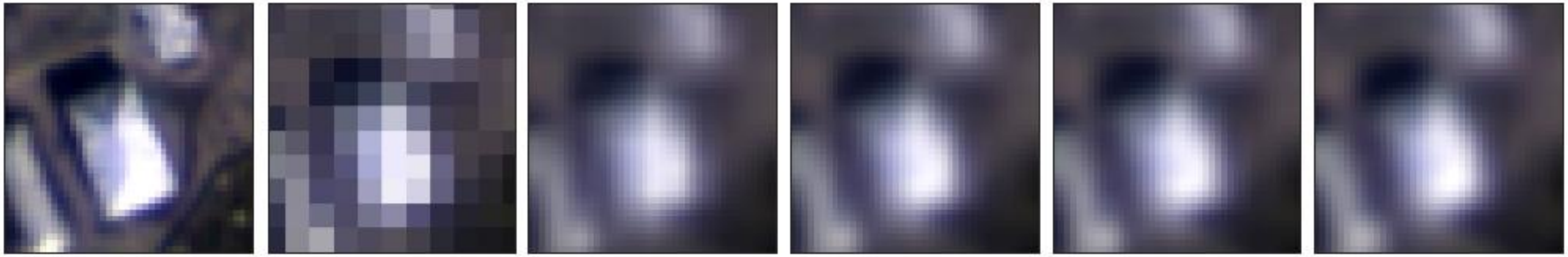
Method	nearest	bilinear	bicubic	lanczos2	lanczos3
MSE	0.0019	0.0017	0.0011	0.0011	**0.0008**
CC	0.9705	0.9755	0.9838	0.9841	**0.9871**
$SSIM$	0.8636	0.8670	0.9111	0.9123	**0.9287**
$cwSSIM$	**0.9999**	0.9997	**0.9999**	**0.9999**	**0.9999**
CC_{norm}	0.9475	0.9615	0.9731	0.9736	**0.9784**

(a) etalon (б) nearest (в) bilinear (г) bicubic (д) lanczos2 (e) lanczos3

I-st stage. Comparing different metrics with using well-known upscaling methods

4-times upscaling

Method	nearest	bilinear	bicubic	lanczos2	lanczos3
MSE	0.0059	0.0056	0.0047	0.0046	**0.0042**
CC	0.9027	0.9126	0.9273	0.9277	**0.9339**
$SSIM$	0.5866	0.6031	0.6529	0.6540	**0.6750**
$cwSSIM$	0.9977	0.9959	0.9987	0.9987	**0.9990**
CC_{norm}	0.8225	0.8582	0.8786	0.8792	**0.8882**

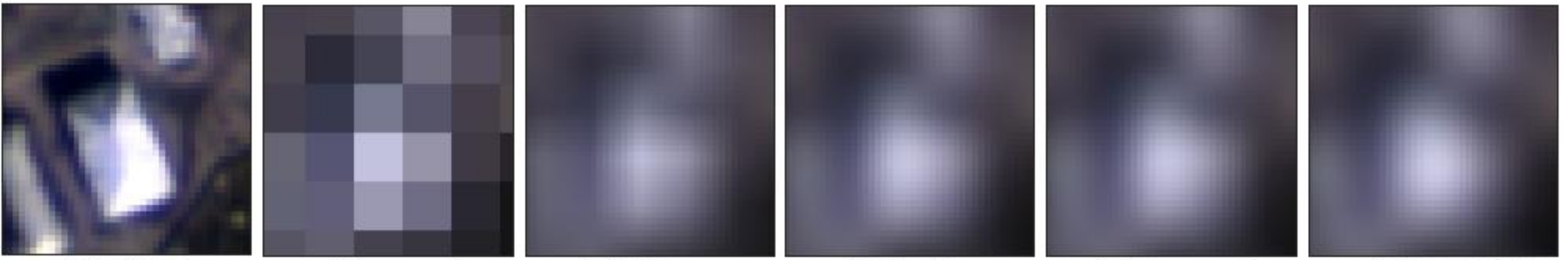


(a) etalon (б) nearest (в) bilinear (г) bicubic (д) lanczos2 (е) lanczos3

I-st stage. Comparing different metrics with using well-known upscaling methods

8-times upscaling

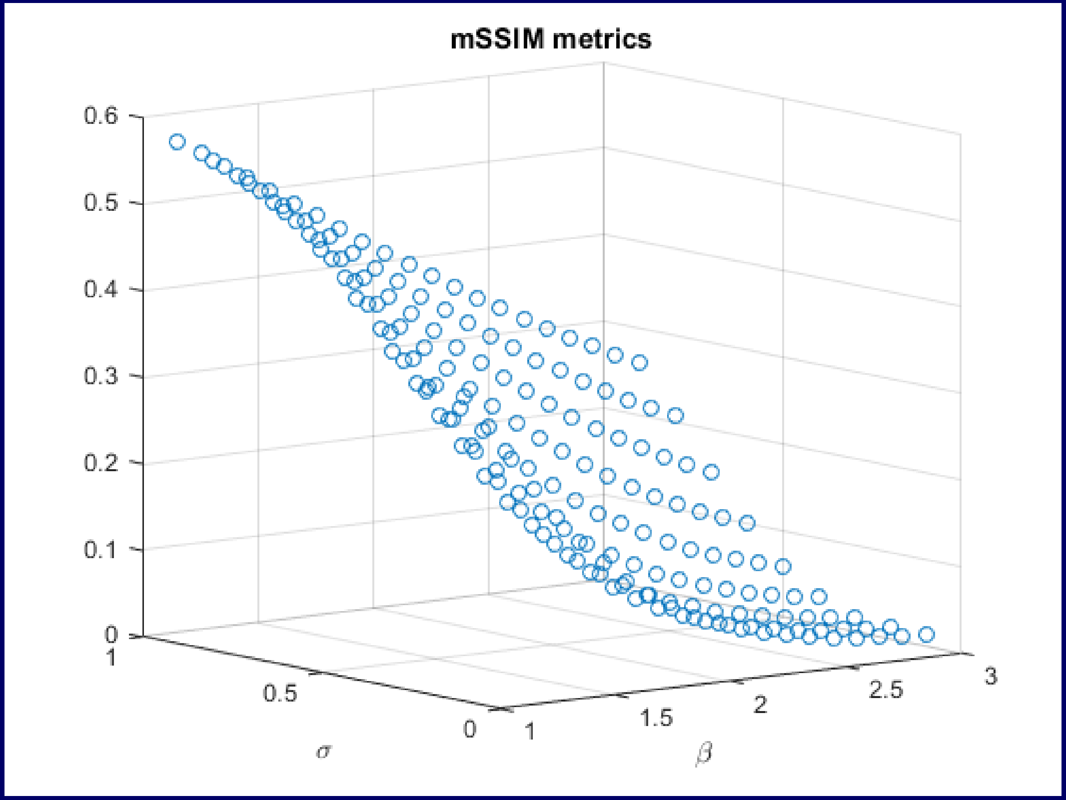
Method	nearest	bilinear	bicubic	lanczos2	lanczos3
MSE	0.0118	0.0115	0.0106	0.0106	**0.0102**
CC	0.7932	0.8049	0.8201	0.8206	**0.8270**
$SSIM$	0.3500	0.3766	0.3979	0.3984	**0.4057**
$cwSSIM$	0.9719	0.9561	0.9762	0.9765	**0.9842**
CC_{norm}	0.5986	0.6529	0.6766	0.6774	**0.6865**



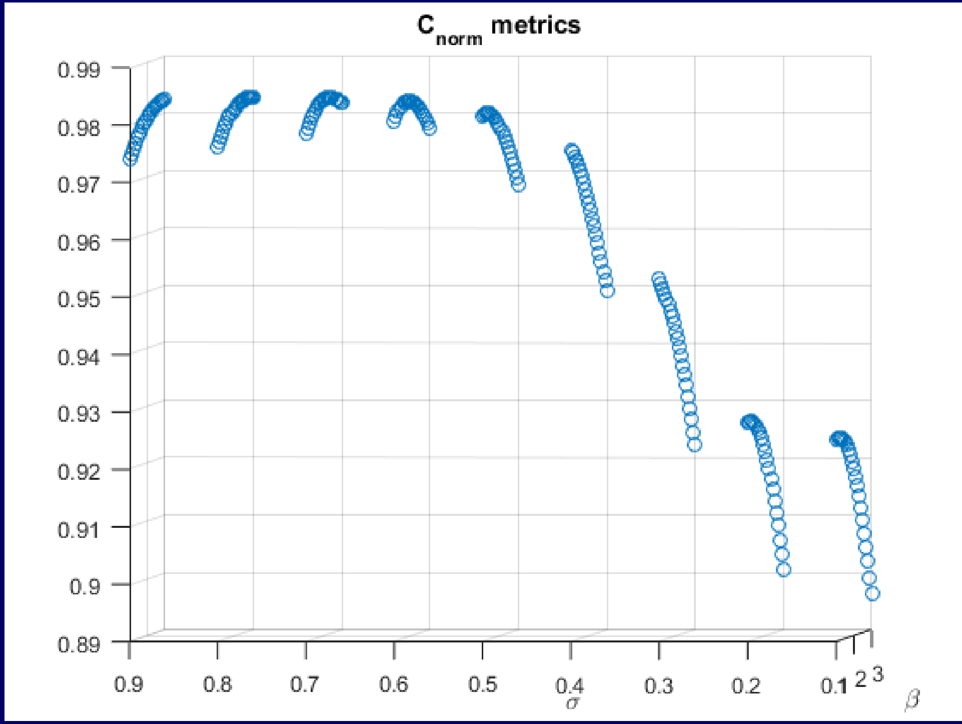
(a) etalon (б) nearest (в) bilinear (г) bicubic (д) lanczos2 (е) lanczos3

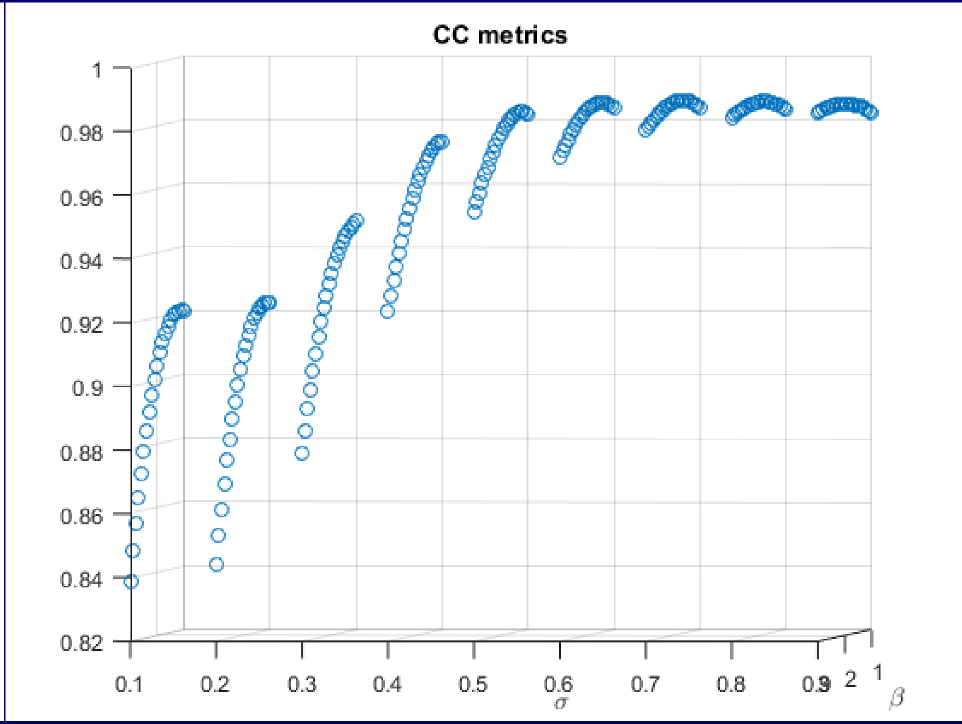
II-nd stage. Tuning of method parameters

$$\left(\alpha_1^*,\ldots,\alpha_K^*\right)=\begin{cases}\arg\min\limits_{\alpha_k} f\left(I_{res}\left(\alpha_1,\ldots,\alpha_K\right)\right), \text{ if } f\left(\bullet,\bullet\right) \text{ shows difference}\\ \arg\max\limits_{\alpha_k} f\left(I_{res}\left(\alpha_1,\ldots,\alpha_K\right)\right), \text{ if } f\left(\bullet,\bullet\right) \text{ shows similarity}\end{cases}$$



II-nd stage. Tuning of method parameters





$$CC_{norm} \Rightarrow \left(\sigma^{*}, \beta^{*}\right)$$

II-nd stage. Experiments

2-times upscaling

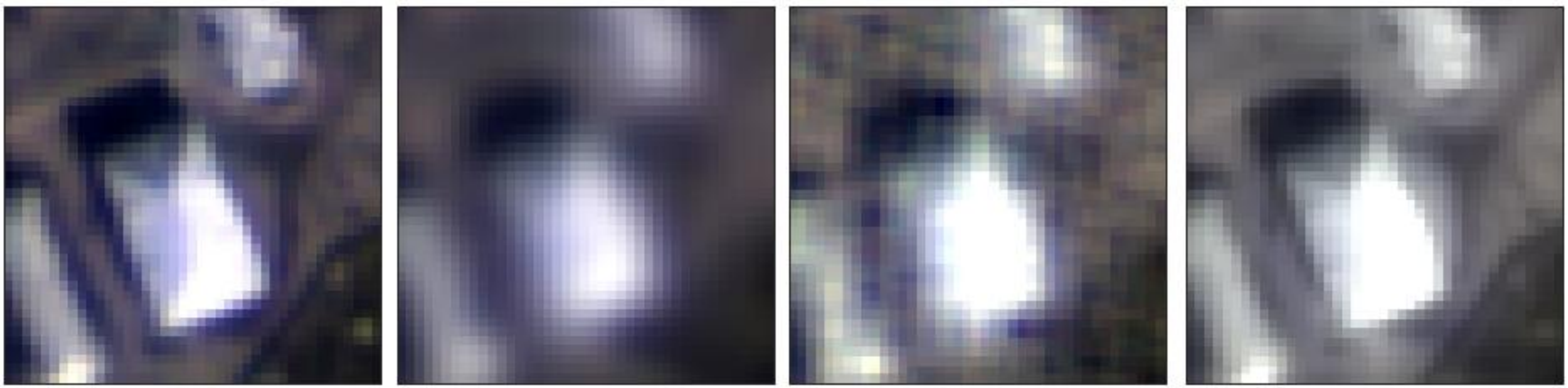
Method	lanczos3	M2	M1
CC_{norm}	0,9784	0,9776	**0,9794**

(а) etalon (б) lanczos3 (г) метод синтеза с экстра поляцией (в) метод слияния

II-nd stage. Experiments

4-times upscaling

Method	lanczos3	M2	M1
CC_{norm}	0,8882	0,8562	**0,9517**



(a) etalon (б) lanczos3 (г) метод синтеза с экстраполяцией (в) метод слияния

II-nd stage. Experiments

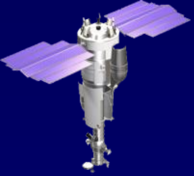
8-times upscaling

Method	M1
CC_{norm}	0,9158

(a) etalon (в) метод слияния

Conclusions

1. Found out approved set of metrics for quality evaluation of suggested image resampling methods.
2. Optimal parameters for M1 method.
3. M1 shows best results when upsampling with optimal parameters.
4. Drawbacks of M1 in color representation.



Thank you for attention!!!