Visualization of the movements of natural objects based on remote sensing data

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Abstract
Methods of constructing vector fields of natural objects' movements based on a series of consecutive satellite images are considered: cloud formations in the atmosphere based on a series of consecutive images obtained from geostationary satellites; water masses and ice fields based on a series of images from low-orbit satellites; using the example of the evolution of bipolar spots, the trajectories of trial corks in the Solar photosphere are constructed based on the data of sounders installed on heliophysical satellite observatories.

Keywords
Natural objects, cloud formation, standard, water masses, ice fields, Delaunay triangulation, trial corks.

1. Moving cloud formations

One of the urgent tasks of space monitoring is to determine the spatial movements of cloud formations in the atmosphere from different-time images obtained from geostationary Earth satellites. According to [1], one of the ways to determine the spatial movements of objects from different-time satellite images is the method based on finding the maxima of the cross-correlation coefficient. In [2], a similar approach is considered as a method of pattern recognition, known as correlation matching. In both cases, correlation is used as a means of finding the equivalents of the standard object represented as an image $w(x, y)$ by dimensions $J \times K$, on the image $f(x, y)$ by dimensions $M \times N$; it is assumed that $J \leq M$ and $K \leq N$. Cross-correlation coefficient

$$\gamma(x,y) = \frac{\sum\limits_{s}\sum\limits_{t}\left[f(x+s,y+t) - f_m(x,y)\right]\left[w(s,t) - w_m\right]}{(JK-1)\sigma_w\sigma_f}. \tag{1}$$

Here w_m — the average value of pixels in the standard w, f_m — the average value of the image elements f in the area covered by the reference. The denominator in (1) uses the product of the standard deviation σ_w of the pixels of the standard w by the standard deviation σ_f of the pixels of the image f in the area covered by the reference.

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In general, the size and orientation of the standard object found in the next image of a series of images may have different values in the subsequent image. The expression (1) normalized with respect to changes in amplitudes is not the same with respect to rotation or changes in the size (scaling) of the standard. In [2] it is noted that "Normalization with respect to dimensions is associated with spatial scaling, which in itself is associated with very time-consuming calculations. Normalization with respect to rotation is an even more difficult task...". Sometimes, to solve the problem of matching (combining) images, taking into account the scaling and rotation of the standard, less accurate criteria are used in comparison with (1), but simpler from a computational point of view (for example, in [3] and a number of other works, the sum of the absolute values of the differences of the corresponding image components is used).

According to [4], the search for the positions of the found standards (determination of offsets) in the next image of the series can be implemented by one of three methods: determining the maximum of the cross-correlation coefficient in the spatial domain, determining the maximum of the cross-correlation coefficient in the frequency domain based on the fast Fourier transform, and finding the minimum of the sum of the squares of distances. The mentioned source also does not assume any standard transformations when searching for offsets, with the exception of the transfer transformation.

In the presented work, the standard displacements are determined on the basis of determining the maximum of the cross-correlation coefficient in the spatial domain in accordance with the formula (1). In this case, the standard can be transformed, consisting of scaling, rotation and transfer. An efficient algorithm based on the scanning rows method has been developed. The obtained results of computational experiments on images from the METEOSAT-8 spacecraft indicate both the need to take into account the scaling and rotation of the standard, and the acceptable time of the corresponding calculations. Level 1B data (10-bit pixels) is used.

The solution of the problem consists of the following basic steps: search square standard objects in the current image W, based on achieving the maximum contrast or maximum entropy; the center of the standard coincides with the center of the square; search for the positions of the found standard in the subsequent image F, based on the achievement of the maximum value of the cross-correlation coefficient; plotting vector fields of spatial movements of objects in accordance with the found positions.

Search for standards. The search for standards is based on the methodology proposed by EUMETSAT [4]. According to this methodology, two types of standards are provided: main and secondary. The positions of the main standards coincide with the ends of the displacement vectors of the standards from the previous image (there are no main standards for the first image).

The search for secondary standard of the *Targ_Size* size is performed in the grid nodes with the *Grid_Size* size. The size of the square area centered at the grid nodes for searching for standards is set by the *Targ_Search* parameter. The allowed minimum distance between the standards is controlled by the *Targ_Dist* parameter. The optimal position for the standard within the search area is the one where the maximum value of the control parameter *Par* — contrast or entropy is reached. When searching for standards within a region of the *Targ_Search* size, local averages and standard deviations calculated from the 3×3 neighborhood are used. Contrast is defined as the difference between the maximum and minimum values of the local averages. In addition to the listed parameters that determine the "physical" characteristics, when searching for standards, the parameters that characterize the "variability" of the image inside the area covered by the standard are used: *Min_St_Dev* — the minimum value of the local standard deviation, *Num_Gr_SD* — the minimum number of pixels with a standard deviation greater than *Min_St_Dev*.

Determination of standard offsets. The offset is determined for each of the *K_Targs* found benchmarks. The search for a new standard position is performed inside a square area of the *Search_Size* size. The center of the search area coincides with the original position of the standard. The new position of the standard is the position where the maximum value of the cross-correlation coefficient *Corr* is reached. During the scan of the search area, the standard is subjected to scaling and rotation transformations. The scale and angle of rotation of the standard are determined by the following parameters: *Scale_Min* — the minimum value of the scale of the standard; *Scale_Max* — the maximum value of the scale of the standard; *Scale_Delta* — the increment of the scale of the standard; *Angle_Beg* — the initial angle of rotation of the standard in degrees; *Angle_End* — the final angle of rotation of the standard in degrees; *Angle_Delta* — the increment of the angle of rotation of the standard in degrees. Since, in general, the transformed discrete grid of the reference does not coincide with the discrete grid of the output image, it becomes necessary to interpolate the pixel values. We offer three ways to get the pixel values of the transformed standard: rounding to the nearest integer; bilinear interpolation; bicubic interpolation.

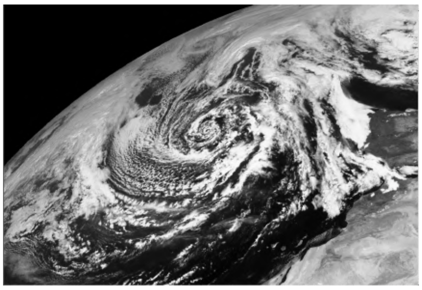

Figure 1: Frame vis006200603151130.

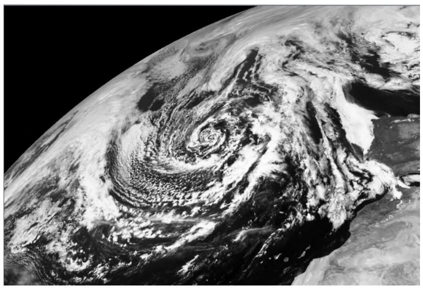

Figure 2: Frame vis006200603151130.

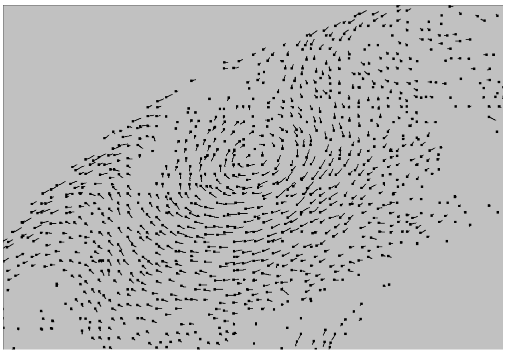

Figure 3: Vector field.

Figures 1–3 illustrate a fragment of the obtained vector field of cloud formations moving in the atmosphere. The process of moving the vortex is demonstrated. The vector field is constructed from five consecutive images from the Meteosat-8 satellite in the optical range (the time interval between the images is 30 minutes). Figure 1 shows the first frame of the image sequence, Figure 2 — the last frame. Figure 3 shows the corresponding vector field.

2. Movement of water masses and ice fields

One of the important uses of satellite data is the monitoring the movement of water pollution and ice fields in marine areas.

The problem of constructing the fields of propagation of marine pollution from different-time satellite data is closely related to the problem of determining the speed and direction of vectors of spatial movements of water masses [5]. Satellite information of the visible, infrared, or microwave (radar data) ranges is used as the initial data in the problem. The method of constructing the fields of spatial movements of water masses based on identifiable changes in some water objects (tracers) on successive satellite images transformed into a single cartographic projection is used. As tracers in optical range images water bodies formed as a result of water blooming (linear and vortex structures of phytoplankton and algae distribution) are used. For infrared images, linear and vortex thermal structures are mainly used as tracers, while for radar images, oil films and films of biogenic pollutants are used.

A similar approach is used in monitoring the spatial movements of ice fields. Here, mosaics, made up of radar satellite images transformed into the same cartographic basis, are mainly used (images of the Arctic Ocean are most often used, because of their importance for the purposes of meteorology and ships navigation).

The process of entering the coordinates of tracer objects consists in specifying their position on the current and next images and saving the entered coordinates in a file that will be used in the final stage of processing and saved for further use.

At the same time, satellite images are pre-made to “fix” the contours of the coastline using reference points, and, thus, on the maps of the distribution of the fields of spatial movements of natural objects, the stationary land is separated from the moving objects.

The Delaunay triangulation is constructed based on the entered coordinates of the objects in the current image. Each triangle of the triangulation corresponds to a triangle in the following image. Such a set of pairs of triangles determined the set of piecewise affine transformations of the plane. These transformations are applied to the nodes of the regular grid in the current image, thereby forming the required displacement vectors.

Simultaneously with the construction of the vector fields of spatial displacements of water masses and ice fields, histograms of the velocities and directions of these vectors can be constructed.

3. Evolution of bipolar spots in the Solar photosphere

Theoretically, the technologies for constructing displacement fields of natural objects presented in paragraphs 1 and 2 can be applied to image sequences of any length. However, in the practice

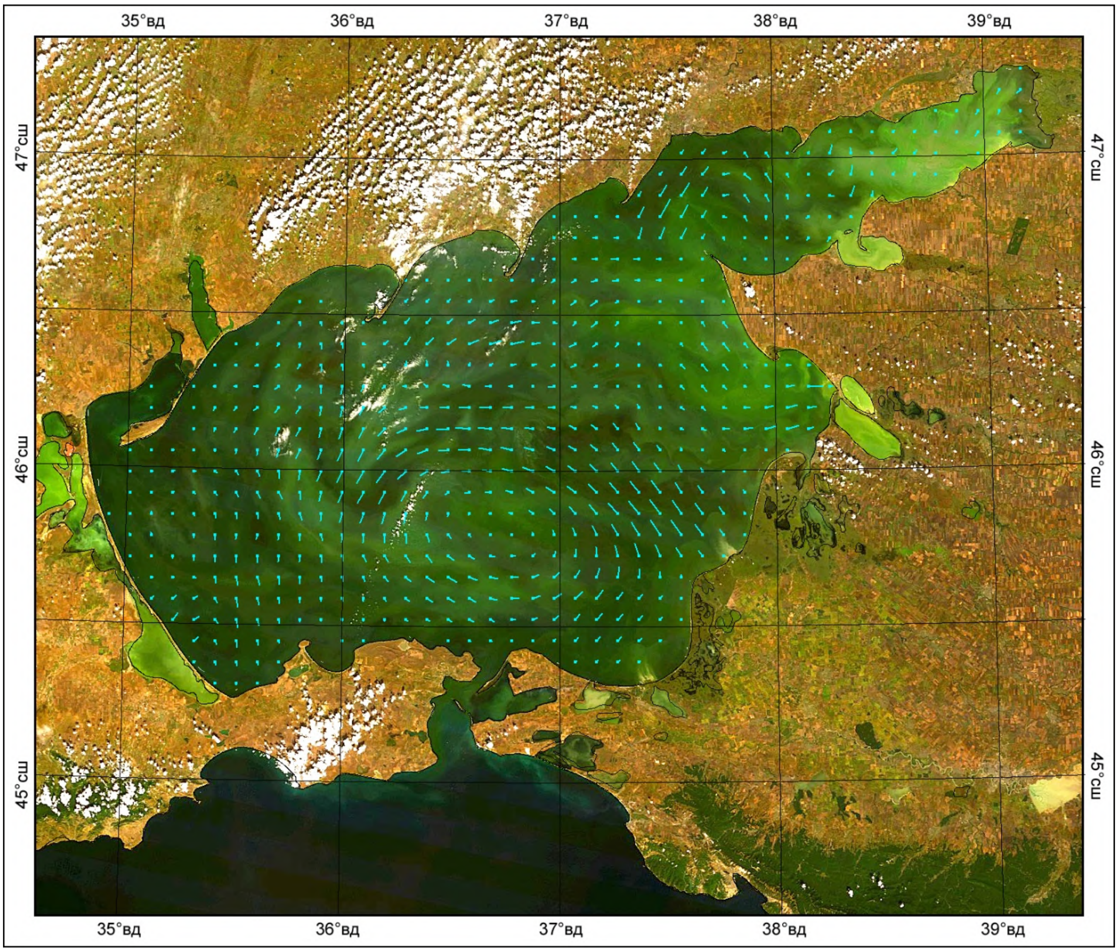

Figure 4: Water mass transfer in the Sea of Azov 08–09.09.2006.

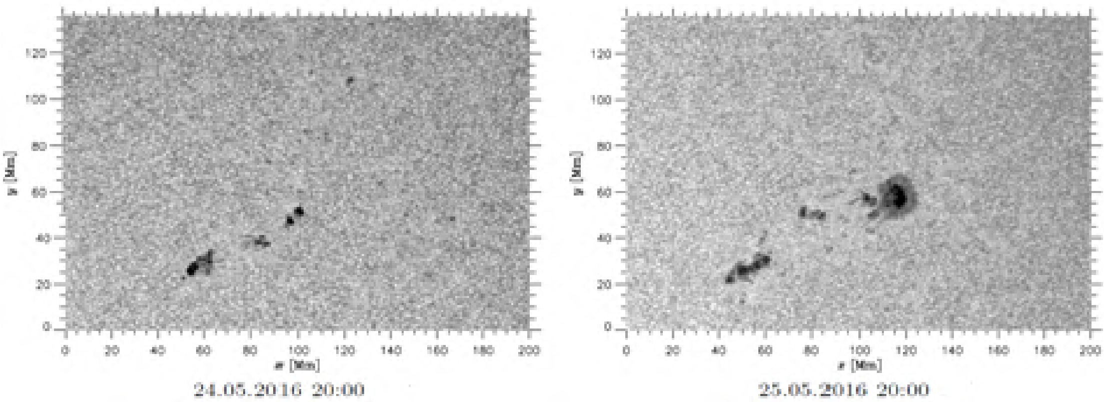

Figure 5: Bipolar group of spots.

of constructing operational hydrometeorological forecasts, for which these technologies were developed, no more than 3–4 images are mainly used. Interactive versions of the corresponding programs are used for this purpose.

But in the processing of data obtained from heliophysical satellite platforms, there is a need to process a series of consecutive images with a length of 100 or more frames. An example is the image of a bipolar group of spots shown in Figure 5. We use here data from the Helioseismic and Magnetic Imager of the Solar Dynamics Observatory (NASA, USA). The goal of processing from the point of view of visualization is to build a field of horizontal velocities of the so-called "trial corks", which at the initial moment are located in the nodes of a regular rectangular grid. As the process progresses, it is necessary to track the trajectory of each trial cork. We considered a series of images of different duration from 2 to 4 hours with an interval of 135 s. between frames [6].

For this purpose, we used a console program [7], which includes the technology of claim 1 and a modified version of the technology of claim 2. The processing parameters are located in a text file, which is a program parameter. For each pair of adjacent images, you must: 1) in the first image, find the standards in accordance with claim 1; 2) find the positions of these standards in the second image by correlation comparison (claim 1); 3) in the first image, build a Delaunay triangulation based on the found positions of the standards; 4) from the obtained triangles of triangulation and the corresponding triangles in the second image, build a set of piecewise affine transformations; 5) for each trial cork, determine its new position by applying a suitable affine transformation. The final stage of processing is the plotting of trial corks trajectories (Fig. 6).

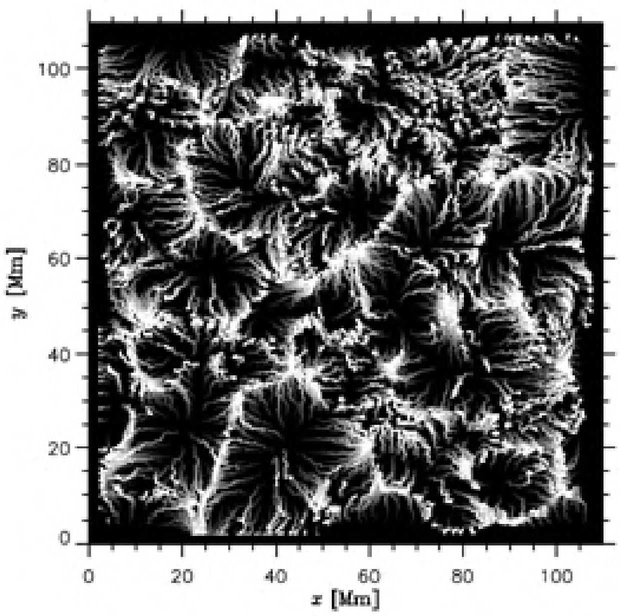

Figure 6: Velocity field of trial corks.

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