Simulation of the flow around 3D surfaces in the study of changes in aeolian relief forms

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Introduction

Processes of interaction at the border of the atmosphere and soil lead to wind erosion, atmospheric pollution by particles of anthropogenic origin, affect desertification and erodibility of soils [1] and should be taken into account when developing paleogeographic scenarios [2].

Relief on small scales [3], [7] affects the mode of wind removal [4], boundary circulation over deserts [5]. Influence wind-sandy flow on process of the aeolian relief formation of the structure is noted in the known models [6], [7].

It is important to take into account local circulation using relief data for local tasks on scales of the order of tens and hundreds of meters, including forecast of extreme events.

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3. Зилитинкевич Э.К., Вагер Б.Г., Утина З.М. Влияние рельефа на профиль скорости ветра // Тр.ГГО. – 1972. – Вып.276. – С.168. – 177.
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1. 3D-model of relief for research and numerical model (NM) for moving flow near surface

Making a surface for NM

Dowload a file **geotif: SRTM Tile Grabber** http://dwtkns.com/srtm/ or **GlobalMapper**

↓

GlobalMapper: cutting, making ***.dew file**

↓

Autodesk Civil 3D: export (2013) file **SLT**

↓

OpenFoam: building a grid, numerical solution

Multiphysics: building a grid, numerical solution

Research of dune moving

Analysis of historical data in **GoogleEarth**

↓

Saving lines of dunes

↓

3D-view of surface

2. Analysis of dune displacement dynamics using historical images Google Earth

Fig. 1. Display surface in GoogleEarth

Base radar images of the surface SRTM (Shuttle Radar Topographic Mission - радарная топографическая съемка большей части территории земного шара

5 areas for study:
Algeria,
Libya,
United Arab Emirates (Sahara desert),
(territory 4),
border of the USA and Mexico (Sonoran Desert),
(territory 5)
China (Takla-Makan desert).

3. Windward Slope Formation Model

1 step: $x(t_0, z_0) \to x(t_1, z_0) = k \cdot x(t_0, z_0)$

2 step: $x(t_1, z_0) \to x(t_2, z_0) = k^2 \cdot x(t_0, z_0)$

$x(t_1, z_1) \to x(t_2, z_1) = x(t_1, z_1) - k \cdot \left(x(t_1, z_1) - x(t_1, z_0)\right).$

3 step: $x(t_2, z_0) \to x(t_3, z_0) = k^3 \cdot x(t_0, z_0)$,

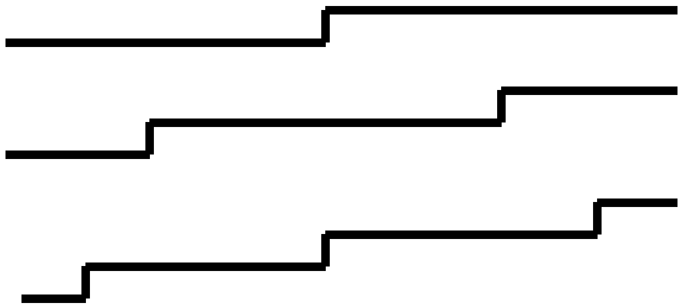
$x(t_2, z_1) \to x(t_3, z_1) = x(t_2, z_1) - k \cdot \left(x(t_2, z_1) - x(t_2, z_0)\right),$

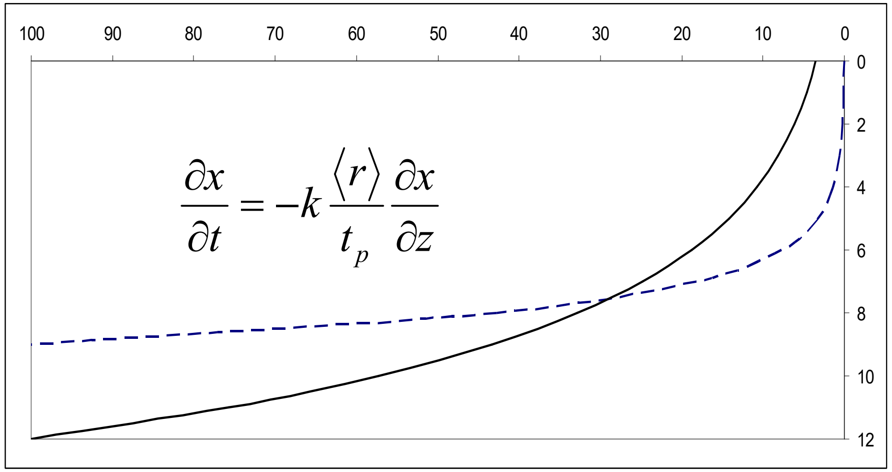
$x(t_2, z_2) \to x(t_3, z_2) = x(t_2, z_2) - k \cdot \left(x(t_2, z_2) - x(t_2, z_1)\right).$

i-th step: $x(t_{i-1}, z_0) \to x(t_i, z_0) = k^i \cdot x(t_0, z_0),$

$x(t_{i-1}, z_1) \to x(t_i, z_1) = x(t_{i-1}, z_1) - k \cdot \left(x(t_{i-1}, z_1) - x(t_{i-1}, z_0)\right),$

$x(t_{i-1}, z_j) \to x(t_i, z_j) = x(t_{i-1}, z_j) - k \cdot \left(x(t_{i-1}, z_j) - x(t_{i-1}, z_{j-1})\right).$





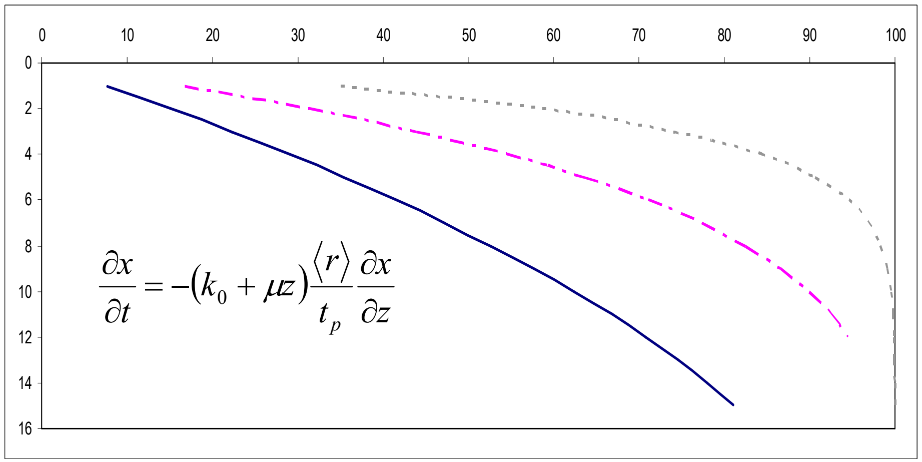


Fig.2. The results of solving the equations of change in the length of the layer in a dimensionless

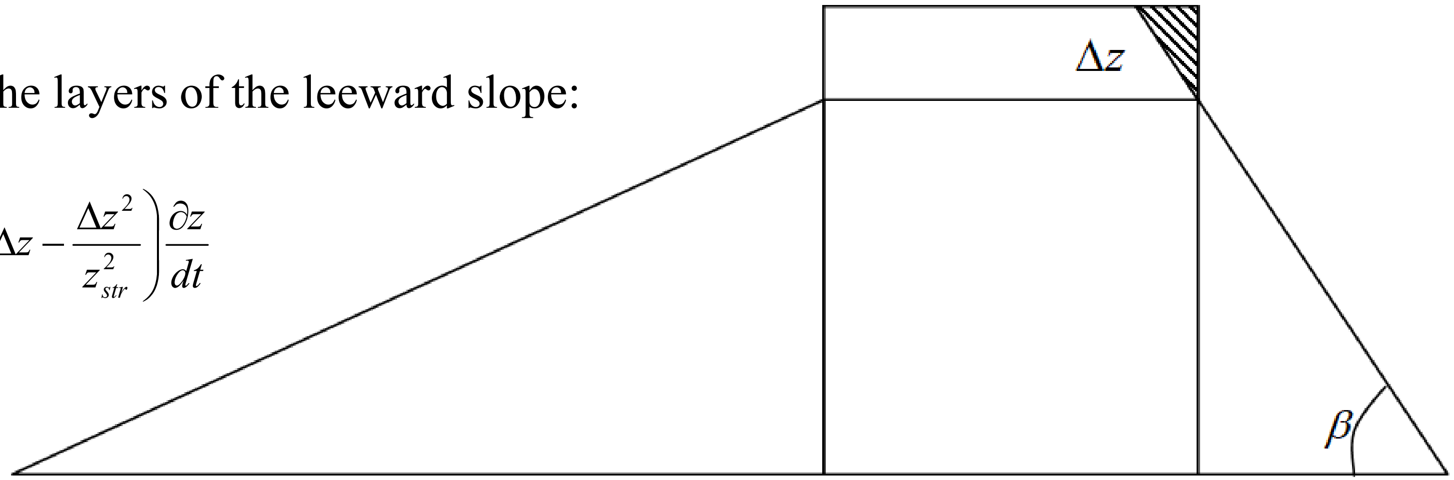
$x(t_0, z_0)$ – the length of the upper layer at the initial time t_0 on high z_0

k – proportion of the length of each new element of the layer,

$\langle r \rangle$ – average particle radius, t_p - average time to detach a particle from the surface

4. Moving the leeward line

$$\Delta x = \frac{1}{2}\frac{\Delta z^2 \Delta k^2}{z_{str}} \cdot \cos\beta \qquad \Delta k = k_L - k > 0 \qquad S_\Delta = \frac{1}{2}\Delta z^2 \Delta k^2 \cdot ctg\beta = \frac{z_{str}}{\sin\beta}\Delta x$$



The velocity of the layers of the leeward slope:

$$\frac{\partial x}{\partial t} = \frac{\Delta k^2}{2}\cos\beta\left(2\Delta z - \frac{\Delta z^2}{z_{str}^2}\right)\frac{\partial z}{dt}$$

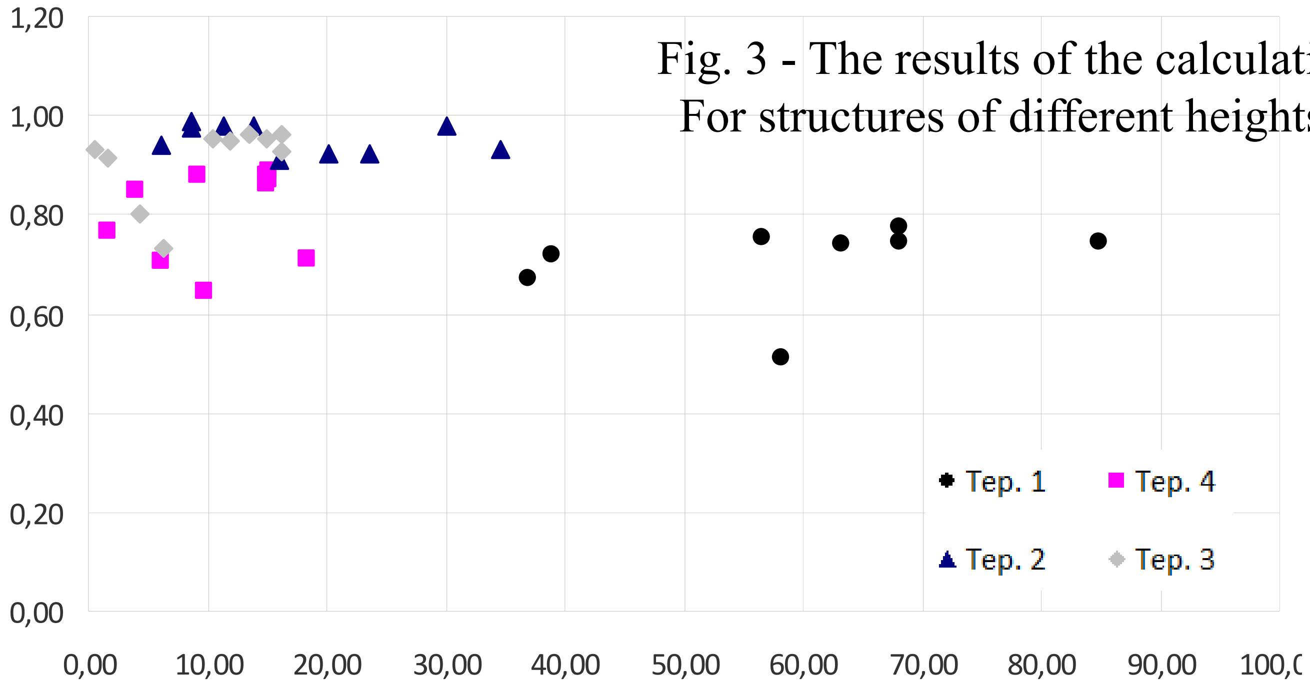


Fig. 3 - The results of the calculation of the coefficient Δk
For structures of different heights from 10 to 100 m.

5. Determination of changes in air velocity during flow around aeolian relief forms based on the analysis of migration data:

Step 1. We determine 1) the change in the coordinates of the location of the boundary of the shadow of the aeolian shape of the relief that outlines the top of the ridge — the top line of the ridge, 2) the change in the width of the shadow, 3) Δx the distance between the ridges.

Step 2. Define $\Delta z'$ - change in height when driving: $\Delta z' = \sqrt{2 \frac{z_{str}}{tg\beta} \Delta x}$

Step 3. Determine the actual change in the height of the structure from direct measurements.

Step 4. Determination of the share of the part involved in saltation taking into account the fall from the leeward side

Step 5. Determine the coefficient of linear velocity change:

$$k = Au_{*0} + B\gamma z + C$$

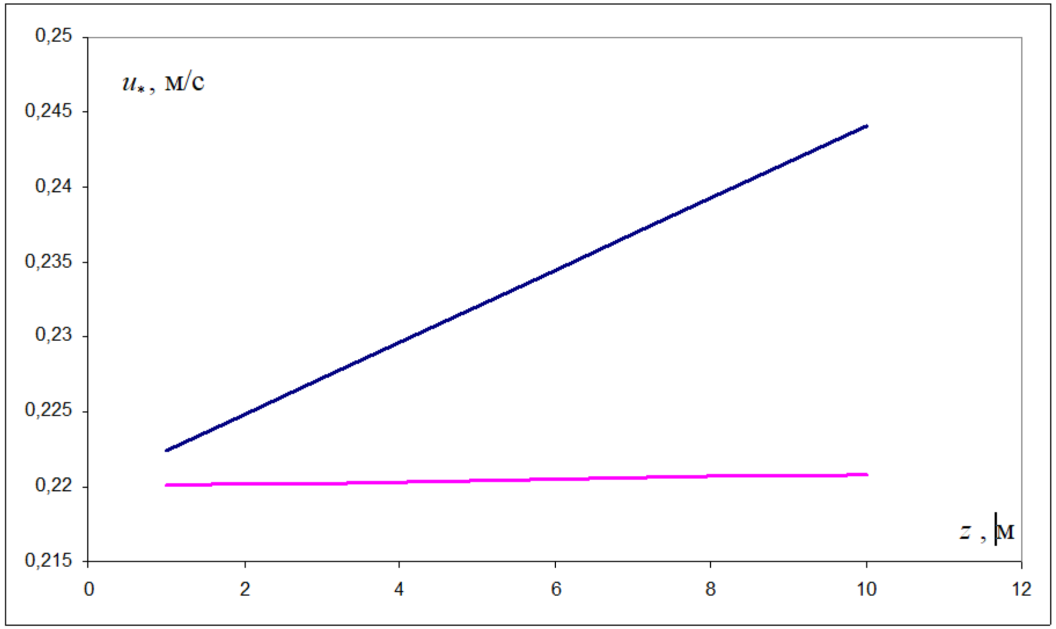


Fig. 4 - Change in dynamic speed when moving up the hill

6. Preparing 3D surface data using GlobalMapper and Autodesk Civil 3D

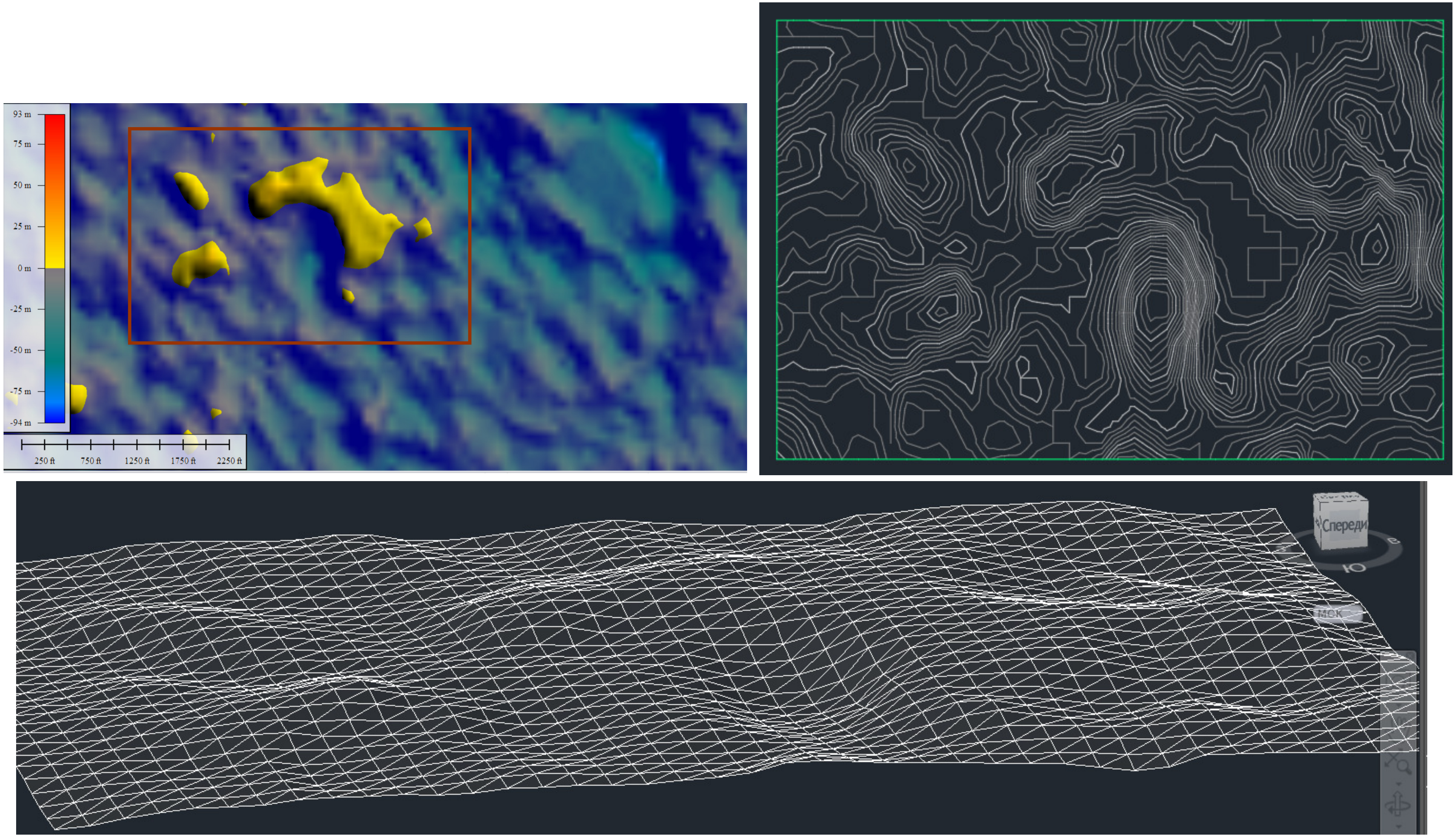
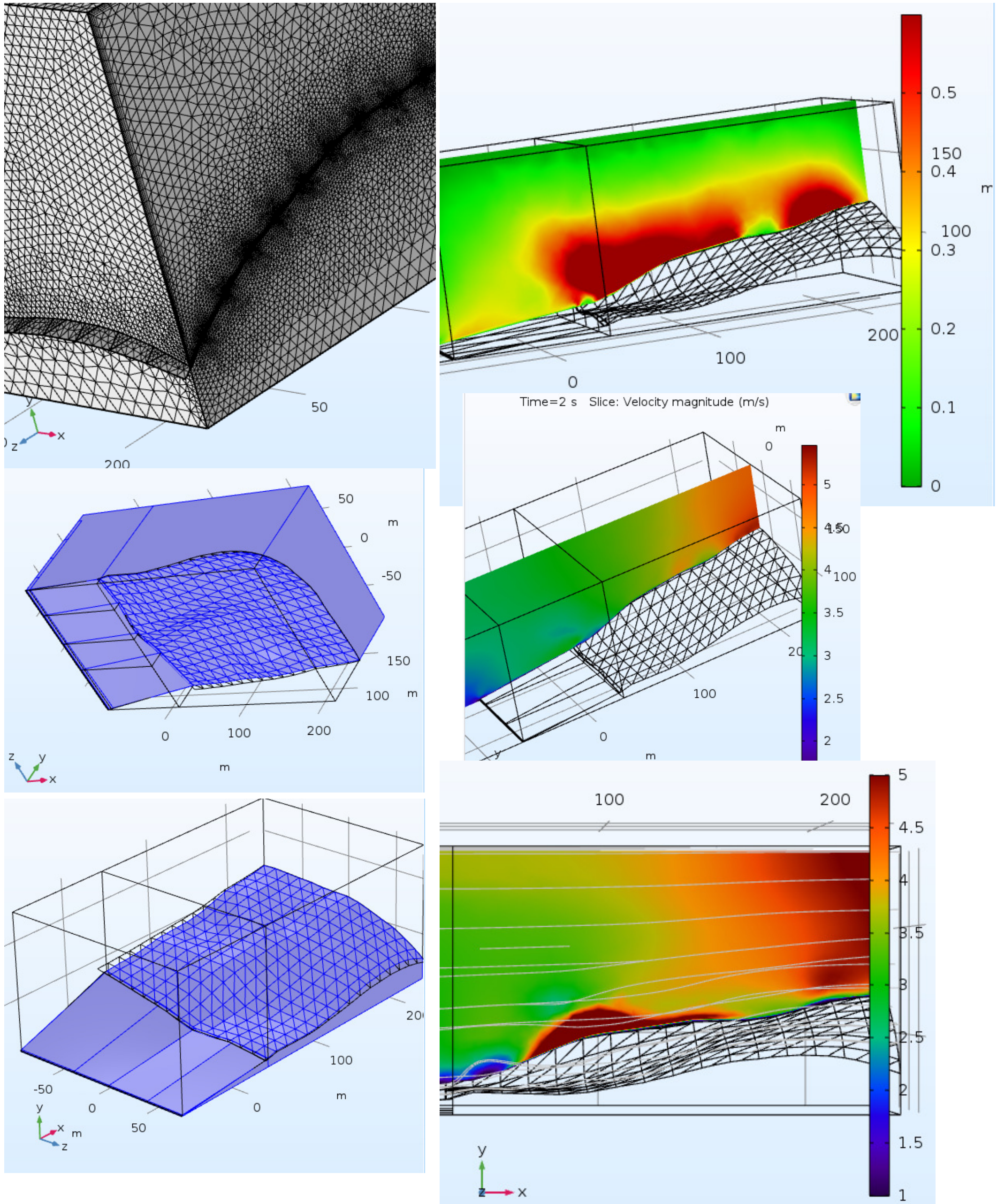


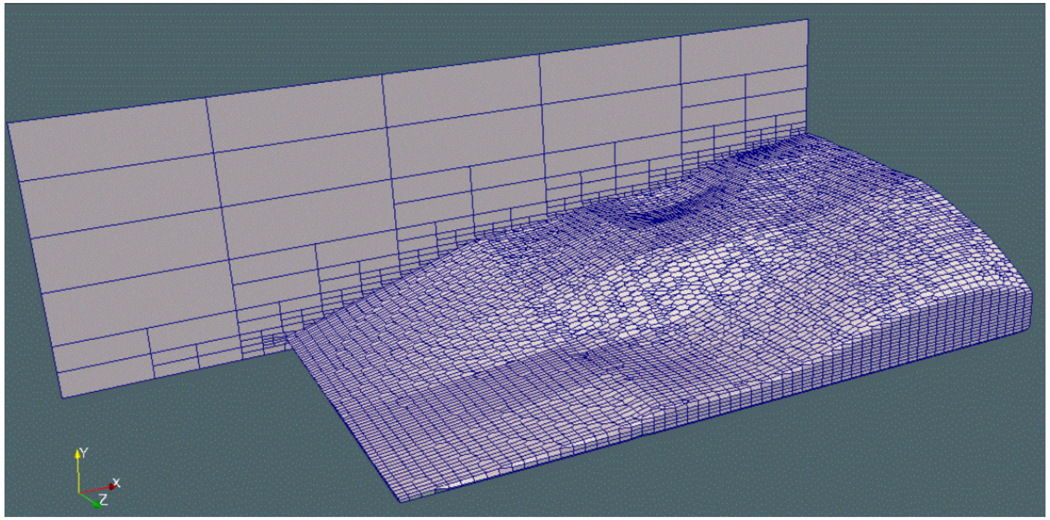
Fig.5 - GlobalMapper display area and its presentation in Autodesk Civil 3D: drawing export (2013)

7. NUMERICAL MODELING



Materials:
block - air,
surface - quartz sand with a surface roughness of 0.3 mm,
Model:
Laminar heat transfer, taking into account the force of gravity.
Border conditions:
the left surface of the block - wind speed of 5 m / s,
right surface of the block - pressure gradient,
sticking to the surface.
Initial conditions:
wind speed 5 m / s, pressure 1 atm.
Training:
“Sandwich” is turned into “butboard”;
flattening 100 m;
empty space 100 m (Air);
gluing together a “sandwich” with volumes of polyhedrons that taper the surface.

OpenFoam NM and grid with snappyHexMesh



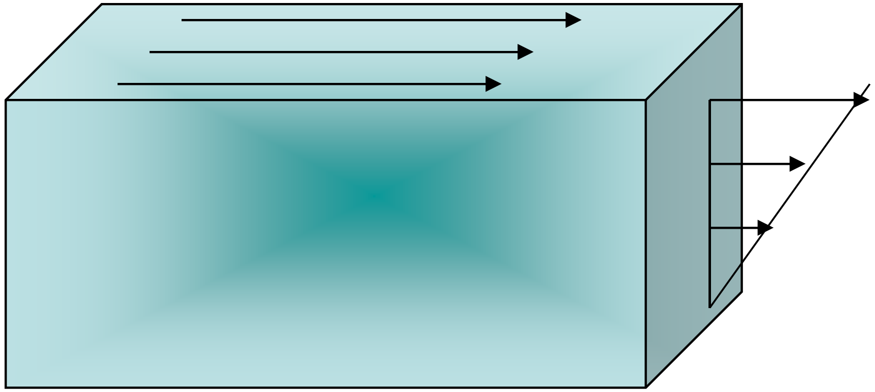
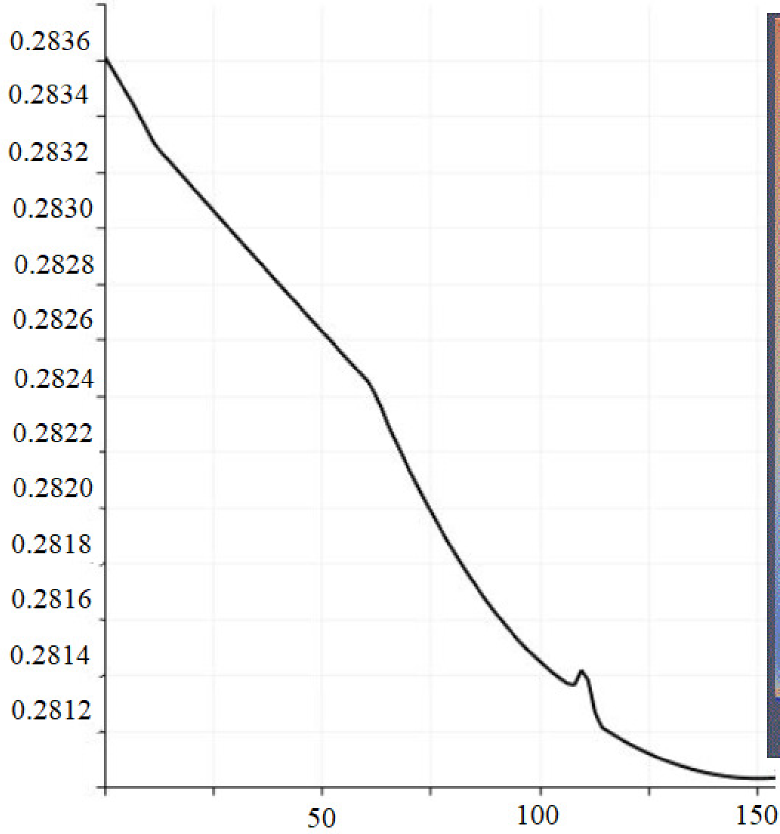


Fig.6 - Adapted to the shape of the surface grid and boundary conditions

The simulation, a laminar flow model with heat transfer.
The boundary conditions:
vertical gradient of the horizontal component of wind velocity (left and right walls),
sticking on the surface.
The open package OpenFOAM, rhoPisoCentralFOAM solver with the ability to use turbulent models, the snappyHexMesh utility for layer-by-layer representation of the grid with adaptation to the surface shape.

A decrease in the friction velocity value when moving up the windward slope



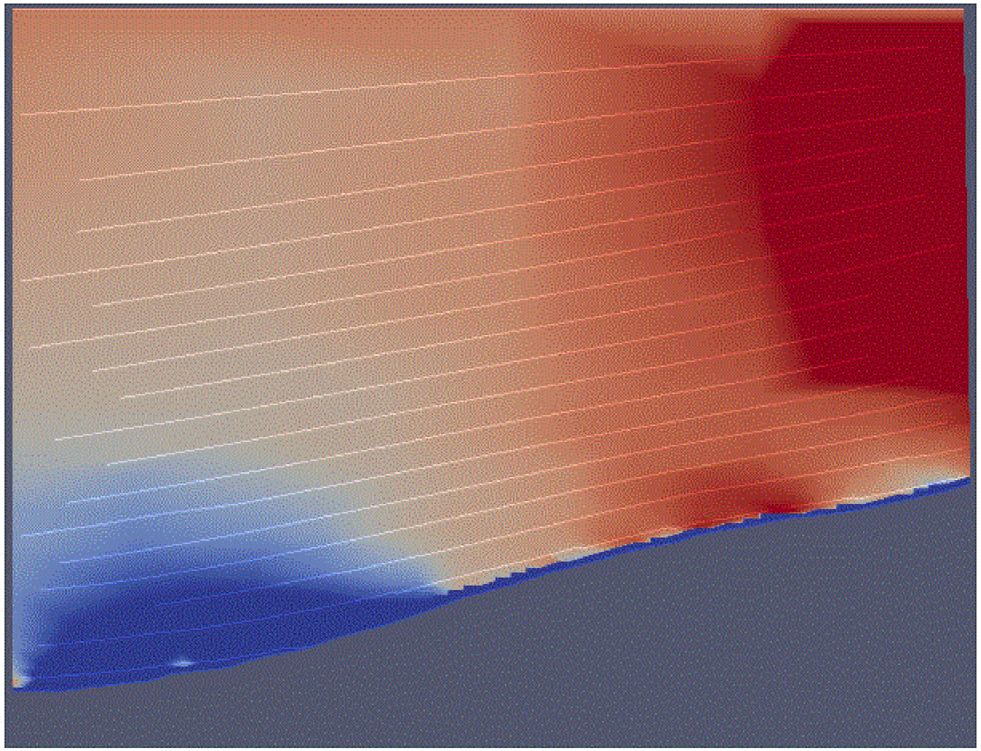


Figure 7 - The dependence of the value of friction velocity from a point up the windward slope. The results of numerical simulation

Conclusion

- Using SRTM images allows you to combine the results of studies of dynamic processes of different scales.
- Historical data for the 10-year interval is taken to assess changes in the eolian relief. Depending on the height of the aeolian structures, the rate of their growth and displacement changes, which is probably due to a change in the nature of the flow and circulation at the surface.
- A detailed study of changes in dynamics is possible, in particular, with the use of modern IT technologies and numerical simulation packages.
- A test laminar flow model with heat transfer implemented using open packages confirms a decrease in the friction velocity value when moving up the windward slope.