Remote Sensing Investigation of the Tunguska Explosion Area.

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ABSTRACT

A multidisciplinary investigation of the Tunguska site (Central Siberia) devastated in 1908 by the explosion of a cosmic body has been carried out in July 14-29, 1999 by the Tunguska99 expedition (see http://www-th.bo.infn.it/tunguska/). In this framework, the remote sensing of a 300-km^2 territory has been performed in collaboration with the Russian "State Research Institute of Aviation Systems" (*GosNIIAS*). An aerophotosurvey and a line scanner survey in 6 spectral bands, from optical to thermal infrared, have been made simultaneously. The 1999 surveys are used to re-examine the 1938 aerophotographic material in order to check details of the 1908 explosion and to verify some recent hypothesis on the event. The 1938 photographic material has been analyzed with the help of the "Tomsk Creative Collective" to obtain new information on the fallen tree distribution. The comparison between the two aerophotosurveys will make it possible to map more accurately the areas with trees surviving the 1908 catastrophe and those with flora variation due to the impact. From this comparison we shall obtain new data on the effects of a cosmic body impact on the forestland coverage, on the spectra reflected from the flora cover, on the Leaf Area Index and other vegetation indices.

Keywords: Tunguska, impact, NEO, aerophotosurvey, forest devastation, fire, LAI, ecosystem dynamics

1. INTRODUCTION

A two-week scientific expedition to the Tunguska explosion site has been carried on July 1999 by the Department of Physics of the University of Bologna, in collaboration with researchers of the Turin Astronomical Observatory and of the CNR Institute of Marine Geology (Figs. 1-3). A camp was built in the taiga, at some hundred kilometres from the nearest roads. Personnel and researchers, mainly from Tomsk (Russia), provided local support. The participants and the equipment were transported from Italy to Krasnoyarsk by a Russian *Iljushin IL-20M* aircraft of the *GosNIIAS* Institute and from Krasnoyarsk to Tunguska by a Russian *MI-26* helicopter. The Tunguska99 expedition was fully financed by the Italian part. Tunguska99 was the technologically best-equipped expedition to the Tunguska area of the last 40 years. It differed from the previous ones by the fact that the investigations were performed simultaneously by water means on the lake Cheko, by ground means and by aerial remote sensing (see *http://www-th.bo.infn.it/tunguska/*).

The main goal of the expedition was to carry out a systematic exploration of the impact site, in order to assess the nature of the body that caused the devastation, felling more than 80 million trees. In spite of the vast amount of theoretical and experimental work done up to now[1], the nature and composition of the cosmic body and the dynamics of the event have not yet been clarified. Some, but no conclusive, data were acquired by the first Italian 1991 expedition[2-3]. The "Tunguska99" expedition[4-5] was organized in order to give an answer about the origin of the Tunguska event, and a contribution to the international research programs aiming at the study of cosmic impacts with the Earth. One of the main tasks of the "Tunguska99" expedition was to carry out an aerophotosurvey and a line scanner aerial multispectral survey (from visible to medium infrared) of the explosion site.

Complementary on-site measurements have been carried out in July 2002 to obtain the coordinates of different reference points in the same area (Fig. 4). These data will allow us to recognise ground elements on the aerial pictures and to connect them to the regional topographic net.

The aims of the present work are to estimate with higher precision the energy released by the explosion and its height, to recalculate the position of the explosion epicentre or of the epicentres, to obtain a 3-D Digital Terrain Model (DTM) on the central devastated area, to map more accurately the areas with trees surviving the 1908 catastrophe and those with flora variation due to the impact. From this comparison we shall obtain new data on the effects of a cosmic body

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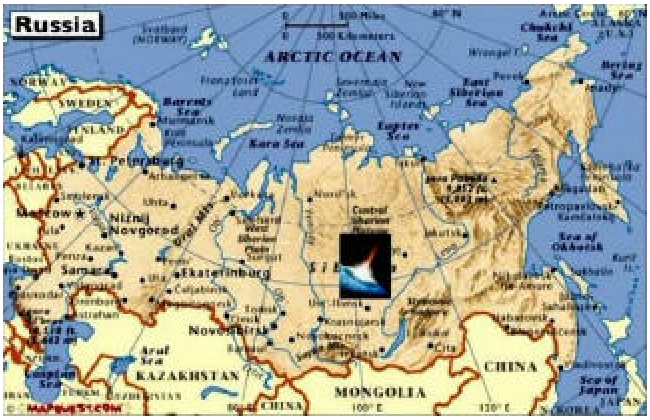

Figure 1: Location of the explosion site (Central Siberian Plateau, Evenkia District).

Figure 2: Planning the work in July1999 (From left: J.Anfinogenov, M. Di Martino, G. Longo, G. Andreev).

Figure 3: The 1999 base camp from where the aero-surveys were directed (photo *A. Chernikov*).

Figure 4: July 2002, M. Serrazanetti and R. Serra measure the exact position of the Farrington astro-radio point.

Figure 5: The Russian flying laboratory *IL-20M* rent by the Tunguska99 Expedition to perform the aerophotosurvey of the explosion site.

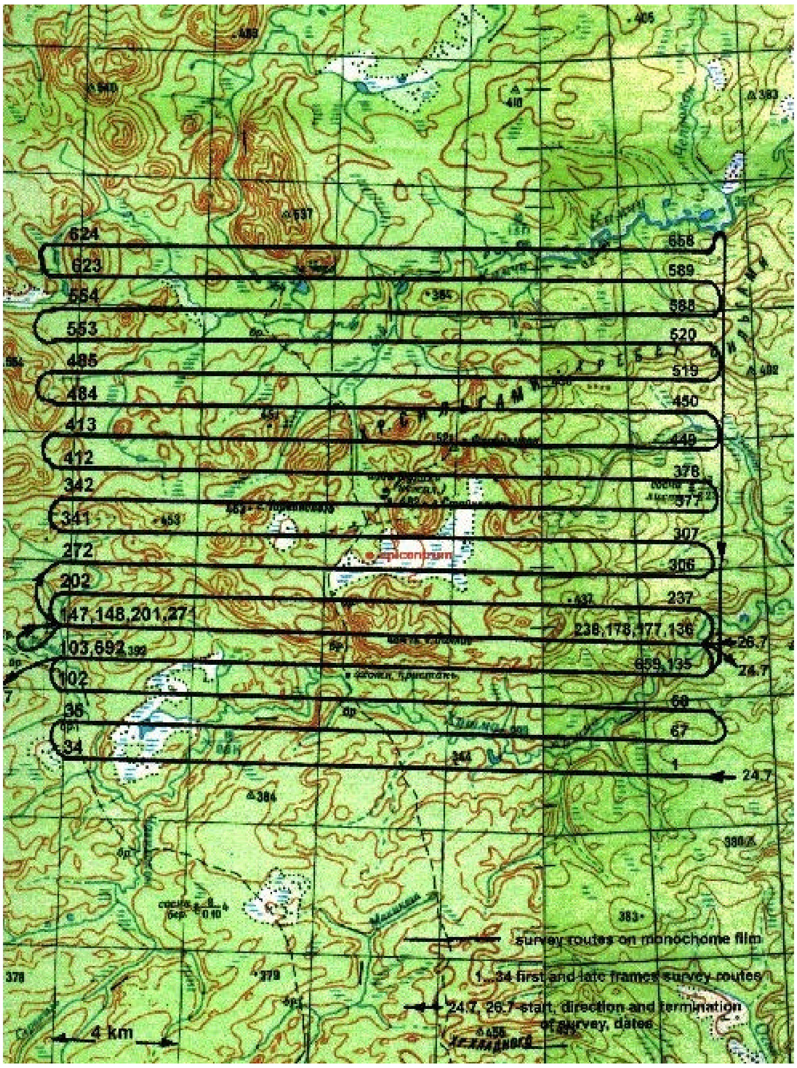

Figure 6: Flight routes of the 1:8000 aerophotosurvey.

impact on the forestland coverage, on the spectra reflected from the flora cover, on the Leaf Area Index and other vegetation indices. To fulfill these tasks we start from three datasets: the 1999 and 1938 aerial photosurveys and Fast's data on forest devastation.

2. DATA

To perform the aerophotosurvey of the explosion site, the Tunguska99 expedition has used the Russian flying laboratory *IL*-20M (Fig. 5). The 1999 aero-photographic survey covered a surface of 300 km^2 between the latitudes 60° 50' 00" N and 60° 58' 30" N and between the longitudes 101°45' 00" E and 102° 05' 00" E (Fig. 6). The photos have been taken in the scale 1:8000 and 1:14000 with coverage of 60% (long.) and 30% (lat.). In parallel, a line scanner made simultaneously a survey in 6 spectral bands, from optical to thermal infrared: 0.43-0.51 µm, 0.50-0.59 µm, 0.61-0.69 µm, 0.76-0.90 µm, 1.5-2.5 µm and 8.0-12.5 µm.

During the flight, the aircraft position was continuously monitored with a GPS system and the geographic coordinates were linked to the photographs. Contemporarily, to recognise ground elements on the aerial pictures, we measured on the site the coordinates of different reference points. This work was completed in July 2002 by a Bologna-Tomsk team (R. Serra and M. Serrazanetti, from Bologna, and G. Andreev, J. Anfinogenov, L. Pavlova and M. Shvedova, from Tomsk) that measured with a 3-5 meter resolution the geographical coordinates of important points on the itinerary Cheko-Kulik's izba-Churgim.

Many aspects of the Tunguska event are being studied by comparing the aerophotosurvey of the explosion site made in 1938 under the direction of L. A. Kulik[6-8] (Fig. 7) with the new one (Fig. 8) performed during the Tunguska99 expedition. The 1999 aerophotosurvey is now used to re-examine the 1938 aerophotographic material in order to check details of the 1908 explosion and to verify some recent hypothesis on the event. For example, we can see in Fig. 7 that the Northern surroundings of the lake Cheko, at the time of Kulik's survey (1938), was covered by the grown forest thus masking some details appearing in Fig. 8 (1999) shot after the site was cleared by a local forest fire (1995). Further information can be obtained from the scanner images in different spectral bands (Fig. 9). The comparison between the 1938 and 1999 aerophotosurveys can shed light on the location of possible secondary "epicenters" of the explosion. Fig. 10 shows a portion of the western part of the Southern swamp photographed on 26 July 1999. Kulik's analysis[6-7] has indicated in this area the possible presence of two secondary centers of wave propagation[3].

The possibility we have to use the 1938 aerophotosurvey is of fundamental importance because it was carried out only 30 years after the event, when the tree trunks overthrown by the shock wave were still easily recognizable on the ground (Fig. 11) and when later falls, not connected with the explosion, have not altered the devastation picture. This allows us to locate the fallen trees and to determine accurately their directions. Krinov, referring to the 1938 survey, stated[8]: "It is a unique scientific document authenticating the only radial forest devastation of its kind in existence and caused by the explosion of a meteorite".

A third database used in our investigations is the forest devastation data collected on-site by Fast and coworkers during 12 different expeditions from 1958 up to 1979. Though Kulik discovered the radial orientation of fallen trees since 1927, systematic measurements of fallen tree azimuths were begun during the two great post-war expeditions[11-12] organized by the Academy of Sciences in 1958 and 1961 and during the Tomsk 1960 expedition. Under the direction of Fast, with the help of Boyarkina, this work was continued for two decades during ten different expeditions from 1961 up to 1979. A total of 122 people, mainly from Tomsk University, participated in these measurements. The data collected are published in a catalogue in two parts: the first one[9] contains the data obtained by six expeditions (1958-1965), which include the measurement of the direction of more than 60 thousands fallen trees on 859 trial areas equal to 2500 or 5000 m^2 and chosen throughout the whole devastated forest. In the second part[10], the data of the areas N° 860-1475, collected by the six subsequent expeditions (1968-1976) were given.

3. FIRST RESULTS

In collaboration with the Russian *"State Research Institute of Aviation Systems" (GosNIIAS)* we have digitalized and archived the results of the 1999 aerophotosurvey. With the help of the *"Tomsk Creative Collective"*, we have digitalized also the aerophotographic survey carried out in 1938 under the direction of L. Kulik and never completely analyzed. To date, 1229 images at 600 dpi from the 1938 survey and 593 images at 700 dpi of the 1999 aerophotosurvey have been digitized and stored (total 34.92 Gb).

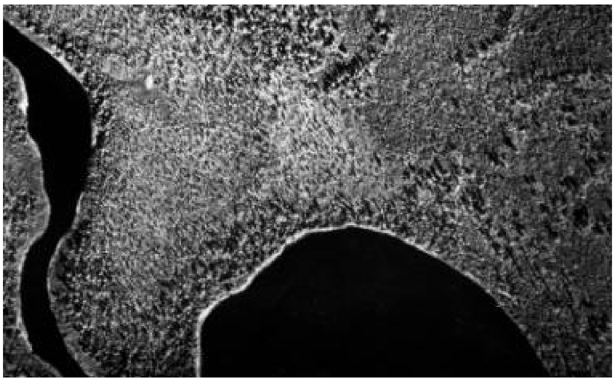

Figure 7: Aerial photo of the lake Cheko (1938).

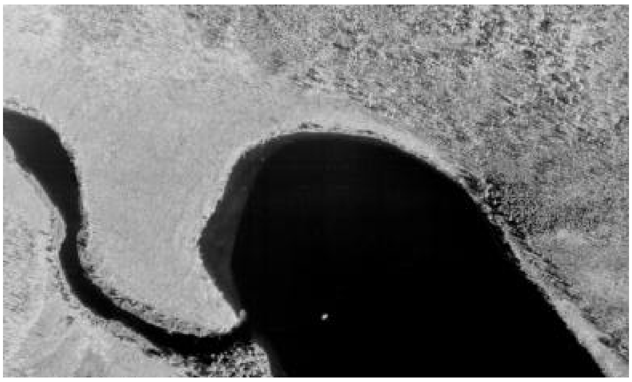

Figure 8: Aerial photo of the lake Cheko (1999).

Figure 9: Scanner aerial picture of the lake Cheko and river Kimchu (1999), spectral band: 0.61-0.69 μm.

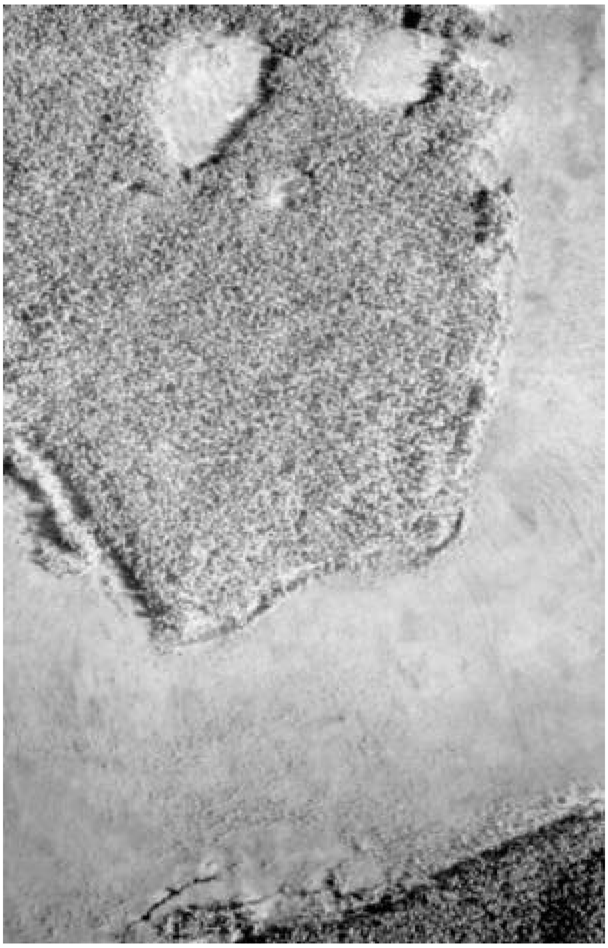

Figure 10: Aerial photo of part of the Southern swamp (1999), where is located the point usually called "Fast Epicentre".

The three datasets mentioned in Section 2 have been checked and completed with our on-site measurements carried out in July 1999 and 2002. An important result obtained in 2002 by the Bologna-Tomsk team is the correction of the Farrington astro-radio point coordinates. These coordinates, measured in 1929 using astronomy and radio time signals, have been used in all the works up to now. The new measurements show that they contain an error of +59 m in latitude and –57 m in longitude.

The 1938 photographic material is releasing important information on the fallen tree distribution and on the location of possible secondary "epicenters" produced by the explosion. A more accurate determination of the forest area destroyed by the explosion will allow us to estimate with higher precision the energy released and could shed light on the impact dynamics. The comparison between the two aerophotosurveys will make it possible to map more accurately the areas with trees surviving the 1908 catastrophe and those with flora variation due to the impact. From this comparison we shall obtain new data on the effects of a cosmic body impact on the forestland coverage.

The map of fallen tree azimuths used in the last 20 years is that constructed by V. Fast and co-workers on the basis of the measured data published in their catalogues[9-10]. Fast's map reproduces only a part of the data obtained from 79000 singletree-measured azimuths. Part of the trial area data was not used due to the rather poor statistics. The published Fast's map was constructed before finishing the measurements reported in the catalogues. Thus the two catalogues contain useful data for 1165 trial areas, while the map uses only the averaged azimuths for 732 trial areas. The remaining data for 433 trial areas have never been used and part of them were rough data without any mathematical elaboration. In collaboration with the *"Tomsk Creative Collective"* we are now completing Fast work. A first new unified catalogue and a map reproducing the averaged azimuths for 1165 trial areas have been obtained[13]. Part of this map is shown on Figure 12. It is worth noting that there are some doubts on the method Fast used for the compilation of his catalogue, that only partially covers some interesting areas, as the "telegraphic pole forest" and the so-called region of "chaotic fall". Now, using the 1938 and 1999 aerial surveys, we are checking and completing the data on forest devastation obtained from Fast on-site direct measurements. The analysis of the 1938 images shows that a considerable part of the imaged area was at that time covered by the grown forest, thus masking the trees overthrown by the explosion. This drawback has been partially overcome with the help of the 1999 aerophotographic survey. On the nineties, in fact, extensive fires affected the Tunguska region and in the 1999 aerophotosurvey there are some places that appear cleared thus allowing to see the fallen trees more clearly than in 1938.

New data on forest devastation will allow an independent determination of the distribution and orientation of the fallen trees and of the coordinate of the explosion epicentre(s).

4. FUTURE WORK

Using the material mentioned above, we plan to perform in the near future the work here summarized:

- To obtain a 3-D fine scale Digital Terrain Model (DTM) on the central devastated area by using the 1999 aerophotosurvey. The DTM will allow performing computational simulations of the Tunguska event and predicting the topographic influence on the refill pattern.
- To search for possible small size impact craters produced by fragments of the cosmic body.
- To apply "ad hoc" explosion models, to estimate with higher precision the energy released by the airburst and its height.
- To develop an automatic pattern recognition software to determine the directions of the fallen trees.
- To attempt to find the cause of the enigmatic "clear spot" revealed in the epicentral area by the Russian satellite ERTS-I (1973).
- To confirm or to exclude the hypothesis that the explosion was caused by the detonation of a large methane cloud ignited by a meteor.
- To compare the vegetation development in the devastated area and in its neighborhoods.
- To perform a comparative analysis of the development dynamics of different forest tracts.
- To evaluate the vegetation biophysical variables, to determine the event ecological consequences.
- To elaborate a project of ecological monitoring and to construct a general model of the effects of impact processes on forest evolution.
- To detect, using the multispectral images, possible anomalies in the forest growth after its devastation.
- To verify the accuracy of the mathematical models concerning the interaction with atmosphere of cosmic bodies having different composition and dimensions.

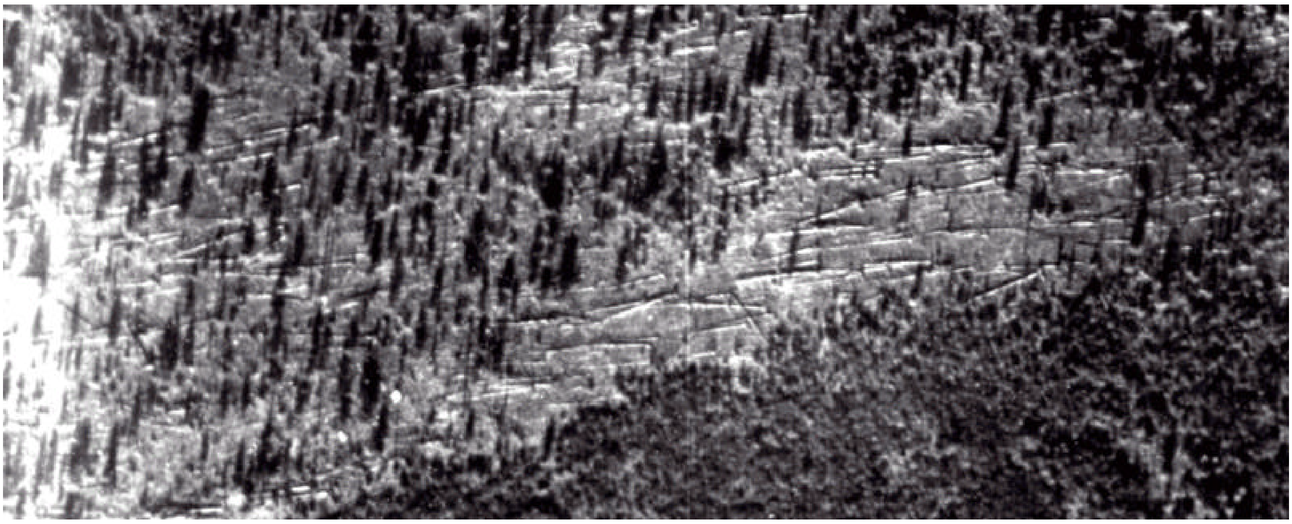

Figure 11: The parallel fallen trees in Kulik's 1938 aerophotosurvey indicate the direction of the blast wave.

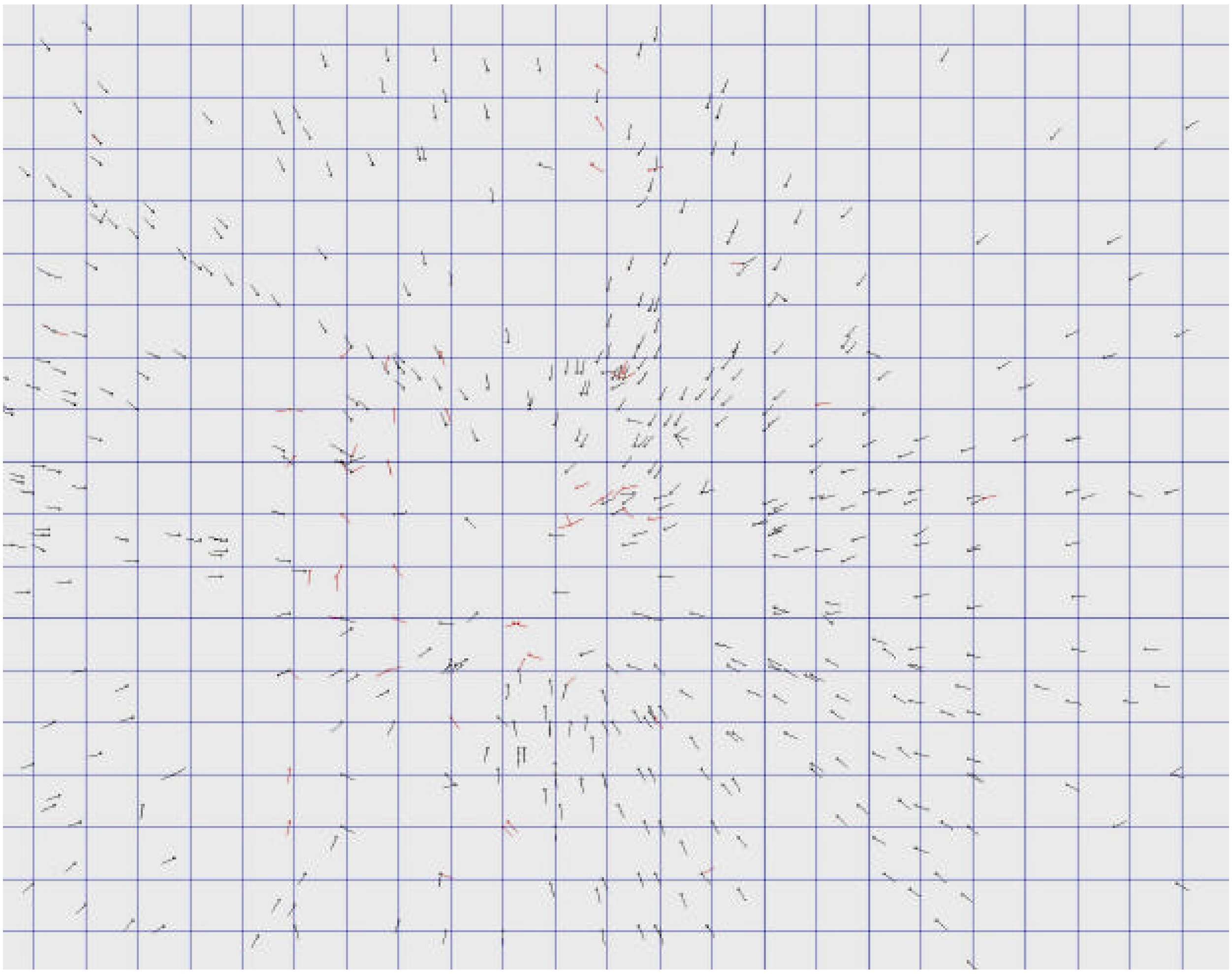

Figure 12: Completed central part of Fast tree azimuth distribution.

5. ACKNOWLEDGEMENTS

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