

## A 3D MODEL OF THE NASCA LINES AT PALPA (PERU)

M. Sauerbier, K. Lambers

Institute of Geodesy and Photogrammetry  
Swiss Federal Institute of Technology Zurich  
ETH Hoenggerberg, CH-8093 Zurich, Switzerland  
www.photogrammetry.ethz.ch  
(sauerbier, lambers)@geod.baug.ethz.ch

Commission V, WG V/6

**KEY WORDS:** Archaeology, Acquisition, DTM, Mosaic, Vector, Visualization, Analysis

### ABSTRACT:

The Nasca Lines or geoglyphs in the desert of south Peru are among the most famous cultural heritage sites in the world. Unfortunately, their investigation and interpretation has been hampered for a long time by the lack of an accurate documentation. Based on aerial imagery that was especially acquired for this purpose, we produced a virtual 3D model of the northern part of the Nasca region, around the modern town of Palpa. The slopes and ridges of this area are covered by more than 1'500 geoglyphs that are shown in the model. This 3D model of Palpa, presented at the workshop for the first time in its complete form, is the result of 5 years of archaeological and photogrammetric fieldwork at Palpa jointly conducted by geodetic engineers of ETH Zurich and archaeologists from Germany and Peru. The model consists of a DTM, photorealistic texture based on an orthomosaic, and a vector layer showing the geoglyphs. These high-resolution datasets are needed to ensure accurate results of the intended archaeological analysis. The overall file size of the 3D model is about 3 GB. Such an amount of data could not be visualized in real time until recently when more powerful hard- and software became available for PC systems. For the Palpa model we use Skyline by IDC, Switzerland, to visualize the terrain and the geoglyphs. The advantages and shortcomings of this software are discussed in the present paper. Furthermore, the use of the 3D model as a valuable tool for archaeological research is described.

### 1. INTRODUCTION

On the south coast of Peru, the Río Grande de Nasca and its tributaries crosscut a vast plain at the foot of the Andean mountains that forms part of one of the driest deserts in the world (Fig. 1). The slopes and plateaus between the fertile river oases of the Nasca region are covered by a spectacular conglomerate of ground drawings of pre-hispanic origin, commonly known as Nasca Lines or Geoglyphs. The drawings or carvings, which were made by removing the upper level of darkly oxidized stones to expose the brighter sandy level below, show a wide variety of sizes and forms: straight and zigzag lines, large trapezoids and rectangles, and biomorphic figures. Though enlisted as World Cultural Heritage by UNESCO in 1994, the meaning of the Nasca Lines is still largely unexplained. Only their cultural affiliation has been reliably established: while the first geoglyphs date to around 400 BC (Paracas Culture), most of them were made during the time of the Nasca Culture (approx. 200 BC to AD 600) (Silverman, Proulx, 2002; Reindel, Lambers, Grün, *in press*). A cultural-historic interpretation of the Nasca Lines is fraught with difficulties, since so far only a few important geoglyph concentrations have been documented in detail, whereas the vast majority of lines and figures remains unrecorded. Any effort to map the geoglyphs by traditional means usually available to archaeologists (like theodolite and measuring tape) faces serious problems, like e.g. the hardly accessible terrain, the sheer number and size of the geoglyphs, and their poor visibility on the ground. Thus, it comes as no surprise that most available maps of the Nasca Lines are of poor quality and show

only a small fraction of the existing geoglyphs. Moreover, the topographic maps of the region lack the required accuracy, too. Without a good documentation, however, any attempt to explain the use and the function of the geoglyphs within their cultural context is conjectural, since the hypothesis cannot be tested against a reliable dataset.

In 1997, ETH Zurich, the German Archaeological Institute (KAVA, Bonn) and the Andean Institute of Archaeological Studies (INDEA, Lima) jointly started a long-term interdisciplinary research project with the aim to record, investigate and interpret the second largest geoglyph concentration in the Nasca region around the modern town of Palpa. More than 700 archaeological sites were registered, and extensive excavations were carried out at several Nasca settlements (Reindel, Isla, 2001; Reindel, Isla, Lambers, 2002). To record the Nasca Lines, well established photogrammetric procedures were applied for the first time in Nasca archaeology in order to generate a 3D model of the Palpa region and its geoglyphs (Grün, Lambers, *in press*; Grün, Sauerbier, Lambers, *in press*). To be useful for archaeological analysis, the 3D model had not only to cover a large area (90 km<sup>2</sup>) in high accuracy, but had also to come with high resolution photorealistic texture (0.25 m footprint) in order to show the archaeological remains in detail. These requirements resulted in a vast amount of data that only recently became processable and visualizable at reasonable cost. In this paper we present the 3D model, discuss its visualization, and show how we use it for archaeological analysis that is hoped to allow new insights into the function and meaning of the geoglyphs.



an area of approx. 90 km<sup>2</sup>. For grid calculation we used DTMZ, an interpolation software developed at IGP that performs Delauney triangulation and finite element interpolation. After the DTM measurements were completed, we merged the data of both blocks to obtain a single DTM for the whole Palpa area. Due to the limitations of DTMZ concerning the number of points, the complete data set could not be processed at once, but instead had to be divided into 8 parts which were interpolated separately. Then, the grids were merged using an ArcView script applying the *Grid.Mosaic* function. The file size of the DTM is about 720 MB.

#### 2.4 3D vector measurement

For a meaningful analysis of the geoglyphs it was necessary to achieve a complete and accurate recording, which again had to be done manually on an analytical plotter. This step resulted in about 20 MB of 3D linear vector data representing the margins of the geoglyphs. The vector data was measured using the XMAP software by Aviosoft and afterwards transferred to DXF- and ArcView-shapefile format for further processing, e.g. for the production of analog maps for archaeological fieldwork. The measurement of the geoglyphs was a complex procedure requiring archaeological expertise in order to map the cultural remains correctly. The problems encountered during the mapping process were manifold: many lines are discontinuous due to erosion, a lot of geoglyphs cut or cover others, and in some cases it is difficult to decide whether a line is a footpath or a geoglyph. Therefore, the measured vectors had to be verified and corrected during 3 field campaigns in Palpa (Reindel, Lambers, Grün, *in press*). Furthermore, in a separate 3D-vector data set we also mapped topographic objects like rivers, roads, buildings, and modern geoglyphs in order to get a complete documentation of the current state of the Palpa area. The file size of the vector data of the modern elements is about 30 MB.

#### 2.5 Orthomosaic

The orthomosaic was generated on a LH Systems DPW 770 digital photogrammetric station after the aerial images had been scanned on an AGFA Horizon scanner at IGP and a ZEISS SKAI scanner at the Federal Office of Topography, Wabern, Switzerland, resp. The scanning was done with a resolution of 21 µm corresponding to a footprint of 0.15 m on the ground. The orthomosaic (2.2 GB) covers approximately the same area as the DTM with a footprint of 0.25 m. It is not only used for visualization purposes, but also for the process of object definition, in which we build 3D polygonal objects from the measured linear vectors (Sauerbier, Lambers, *forthcoming*).

### 3. VISUALIZATION OF THE 3D MODEL

The 3D model of the Palpa region consists of the DTM, the orthomosaic texture, and the vector data, all in all about 3 GB of data. During the past few years we generated several visualizations of preliminary or partial data sets with ERDAS IMAGINE Virtual GIS (still images) and Open Inventor on SGI (flyovers). Currently, we employ Terra Explorer by Skyline for real time visualization of the complete 3D model.

#### 3.1 ERDAS IMAGINE Virtual GIS, Open Inventor on SGI

The first static visualizations of the 3D model, mostly small subsets of the total area containing only a few geoglyphs, were processed with the ERDAS IMAGINE Virtual GIS version 8.4 by Leica Geosystems. This system yields good results but is

quite limited concerning the size of the data set. Nevertheless we use it for the production of still images (Fig. 3; see also examples in Reindel, Lambers, Grün, *in press*; Grün, Sauerbier, Lambers, *in press*). A real time navigation through the complete 3D model is not possible using the ERDAS system. As an alternative we visualized the Sacramento part as well as the San Ignacio part transformed to Open Inventor format on an SGI Onyx 2 computer with the SceneViewer and Perfly tools. Unlike ERDAS or Skyline (see below), these tools do not use the *Level of Detail* technique to partly reduce the resolution of the model but instead render the complete model in its original resolution. To come close to real time performance, the resolution of the DTM had to be reduced to 20 m, so these models could only be used for overviews since details were not recognizable in acceptable quality. The advantage of SceneViewer is its capability to display 3D models in stereo mode, which allows observers to get a spatial impression. One of its main disadvantages is the missing option to display vector data.

#### 3.2 Skyline

Currently, for real time visualization of the complete 3D model we use the Terra Explorer Pro / Terra Builder software package by Skylinesoft, distributed in Switzerland by IDC AG, Luzern (Skyline Software Systems Inc., 2001). The Skyline software was chosen because it is one of the first visualization packages that runs on conventional PC architectures even with large datasets in real time mode. Furthermore, unlike with most other products in this segment, the user is able to generate and edit the 3D model on his own without depending on the service of the software distributor. In general, the requirements of the Nasca-Palpa and other IGP projects are largely met by the Skyline software package. It is to be expected that most of the problems encountered during our work (described below) will be resolved with future versions of the program.

The Terra Builder is used to import the data (DTM, orthomosaic, vector data) and to render the textured 3D model. Table 1 shows the data formats and some further technical features of the Terra Builder.

Feature	Specification
Coordinate Systems	<ul style="list-style-type: none"> <li>– Planimetric or spheric</li> <li>– UTM, custom coordinate systems can be defined</li> </ul>
DTM Formats	<ul style="list-style-type: none"> <li>– Grid data: XYZ-ASCII files, Z-ASCII files (dimensions, coordinates of upper left corner and mesh size are given manually)</li> <li>– DTED (US military format)</li> <li>– BMP, TIFF (gray values)</li> <li>– RAW plug-in allows the import of other formats (RGB, Byte, Floating Point, Double Precision)</li> </ul>
Image Formats	<ul style="list-style-type: none"> <li>– BMP</li> <li>– MrSID</li> <li>– TIFF</li> </ul>
Vector Formats	<ul style="list-style-type: none"> <li>– ArcView Shapefile</li> <li>– DXF (AutoCAD R12)</li> </ul>
Geo Reference	<ul style="list-style-type: none"> <li>– Worldfile (tfw): unit per pixel, rotation, coordinates of upper left corner</li> </ul>
Clipping Methods	<ul style="list-style-type: none"> <li>– Rectangle</li> <li>– Polygon with feathering</li> </ul>

Table 1: Technical features of Terra Builder

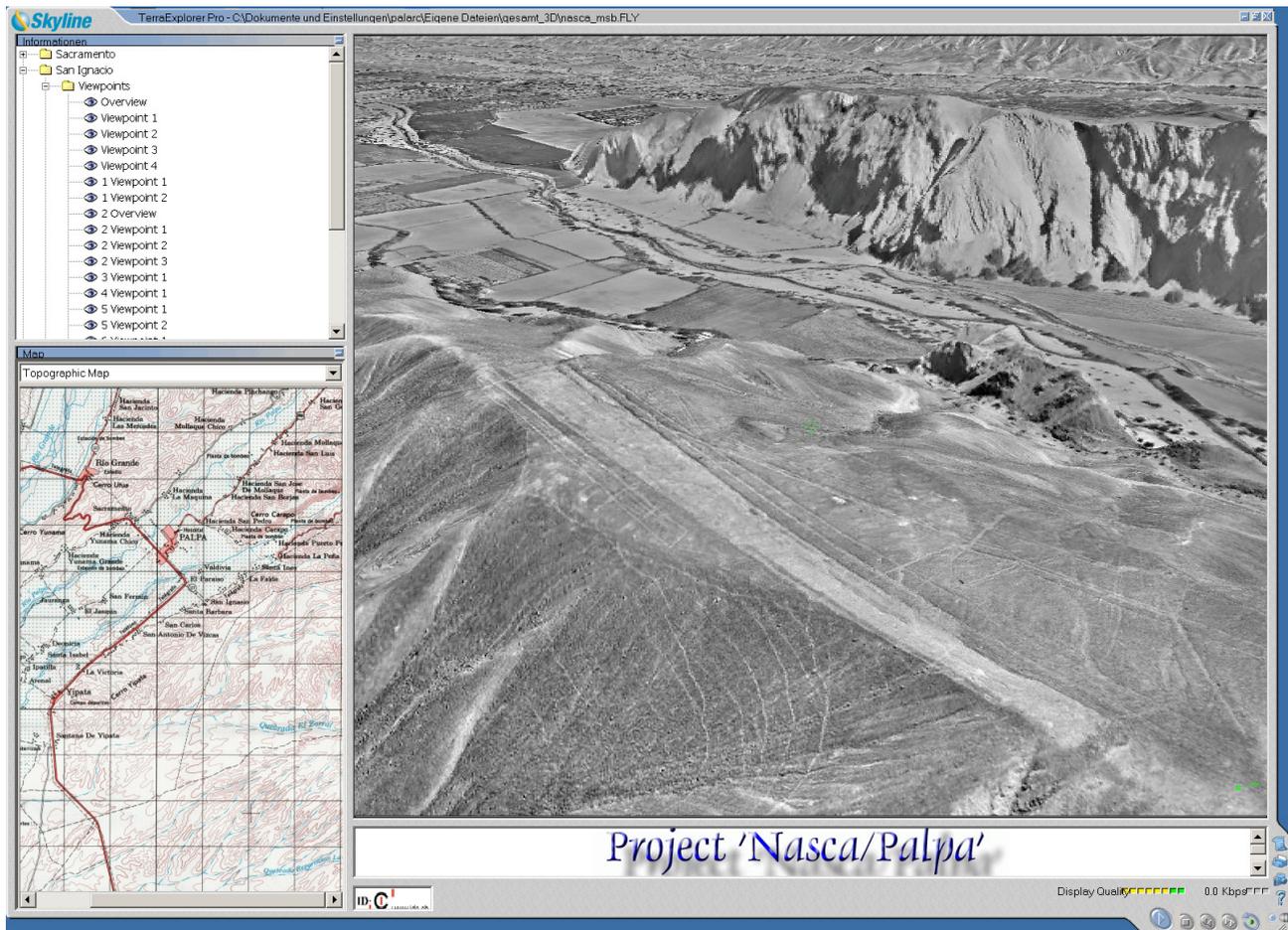


Figure 2: User interface of the Skyline Terra Explorer Pro (showing geoglyphs on the Pampa de San Ignacio)

Several useful tools support the production of a correct 3D model, e.g. radiometric feathering for images with different radiometric properties or different resolution and for the creation of a smooth boundary for the model. Another helpful tool is the clipping of areas using polygons to cut out subsets of the whole area. The processing of 3D vector data can be managed in two different ways. One is the integration of the 3D vectors into the DTM, importing the vectors' height attributes. This allows the display as real vectors with the result that lines appear as thin lines with a constant thickness, independent of scale. The other method is to omit the height attributes of the 3D vectors and project them on the DTM surface. As a result they appear fragmented to single pixels inside the texture so that each pixel has the same size as one pixel of the orthomosaic. A radiometric correction of images can only be done via two sliders (to adjust luminosity and gamma, resp.), so especially for radiometrically heterogeneous color imagery it is recommendable to import already corrected images. Terra Explorer Pro allows the integration of additional information: on the one hand into the 3D model itself (e.g., text labels, Quick Time files, moving 3D objects), on the other hand via lateral windows (e.g., georeferenced maps, web pages; see Fig. 2).

A strong point of the Skyline software is its performance regarding real time visualization of very large datasets. The 3D model is loaded to random access memory in a data stream continuously. This method allows for a real time performance that is almost independent of the amount of data. Nevertheless, it is possible to split large datasets into smaller parts. The

splitting of datasets should be applied if the file size exceeds 2 GB according to the recommendations of the software distributor. A limiting factor is the size of vector layers, e.g. city models with a large number of buildings and textured facades. The streaming technology enables the user to access remote data sources via network or Internet. In this case, the performance of real time navigation depends on the transfer rate of the available network connection. A disadvantage of Terra Explorer Pro is the reduction of the original resolution of the orthomosaic texture while displaying the 3D model. This is handled in a better way by other software, e.g. Terrainview by ViewTec.

To use current PC systems for the visualization of large datasets requires the partition of the 3D model. The Skyline software offers two possibilities to apply *Level of Detail* (LoD): a constant LoD for the whole scene, or a dynamically adapted LoD depending on the position of the viewer. In real time mode, the second method works with good results so that the borders of different levels of detail are hardly visible, but in recorded image sequences they appear very clearly.

The production of synthetic flyovers of high quality is an important requirement of the Nasca-Palpa project. The Terra Explorer Pro is a comfortable tool for this purpose. In order to produce a synthetic flight through the model one can create a flight path and record a flight along it to an AVI file. The flight path can be shown and edited in real time mode. It can be defined via a coordinate table or by navigating with the keyboard and storing either waypoints or the whole path. The most efficient method to obtain a smooth path is to fly through

the model by keyboard, storing waypoints, and afterwards to iteratively adjust the parameters of the waypoints in the table. For every point between these waypoints, the parameters (coordinates, speed, acceleration, camera angles, and turn speed) are linearly interpolated. To obtain a smooth navigation through the 3D model the user has many options to adjust the flight parameters like acceleration, deceleration, turn speed, maximum speed and minimum/maximum altitude, but unfortunately, there is no possibility to adjust the turn speed parameter of the camera for each waypoint individually, which causes jerky rotations. Nevertheless, with some experience it is possible to produce image sequences that run very smoothly and without jerk.

An alternative to the use of the keyboard is joystick navigation. The joystick should provide the user with a more intuitive facility to move through the 3D model than by using the keyboard. We tested a Logitech Wingman Extreme especially developed for 3D computer games like flight simulators. In Terra Explorer Pro, the user can easily adjust acceleration, speed, and rotation speed presets, and with some experience it is possible to fly through the model smoothly. A problem occurs if the roll or pitch angles change quickly. In this case the background appears fragmented. This effect results from the fact that the image background is not rebuilt again in every newly rendered frame so that fragments from previous frames remain in areas where sky would be expected. With keyboard navigation, this effect does not occur, since such movements are not supported.

A significant problem that we encountered is aliasing, which is not solved in a satisfying way. The problem occurs mainly when navigating over planar areas in a flat viewing angle. The aliasing effect especially disturbs the display of vector layers and of areas (3D faces). On the other hand, a software-side antialiasing algorithm would decrease the real time performance significantly.

For the production of screenshots it would be desirable to optionally change the resolution of the resulting images, which is not possible in the current version of the Skyline software.

### 3.3 Hardware specifications

The hardware resources required by the Skyline software do not exceed the capabilities of common PC systems. It runs on Microsoft Windows operating systems and can use data from DVD-/CD-ROM, harddisk, or via network or Internet. In our case it runs on a PC with a 2 GHz Intel processor, a Nvidia Quadro 2 Pro graphics card with 64 MB texture memory, and 512 GB random access memory. The monitor has a 21 inch diagonal, which enables the display of 1'600 by 1'200 pixels for detailed views in high resolution.

## 4. USE OF THE 3D MODEL

The accurate, photorealistic 3D model of the Palpa region serves basically two purposes: public presentation and scientific research.

### 4.1 Presentation

Though based on black and white images, the 3D model gives a very realistic impression of the area of investigation due to its accuracy and the high-resolution orthomosaic used as texture (Figs. 2, 3). Moving through the model allows reconnoitering the valleys, the ridges and the plateaus of Palpa and seeing the terrain and the geoglyphs in great detail. Navigating in real-time mode or via pre-recorded videos, one can virtually ascend from the valleys to the plateaus, which gives a much better idea of the landscape and its characteristics and dimensions than the usually shown photos of the Nasca region taken from airplanes.



Figure 3: View of a geoglyph site on the Pampa de San Ignacio generated with ERDAS Imagine 8.4

The biggest advantage of the 3D model is its mobility: it can be shown everywhere and allows people who cannot or do not want to travel to Palpa to get to know the region all the same. A preliminary version of the 3D model has already been shown with great success on a big screen on occasion of a Nasca exhibition in Zurich in 1999 (Rickenbach, 1999). In the Palpa region, a virtual flight through the 3D model can substitute a real flight over the region that many people cannot afford. The final version of the model will be presented in the new site museum in Palpa, which is currently being established (Reindel, Isla, Lambers, 2002). It is hoped that the model will help to make the local population aware of the richness of their cultural heritage and of the need to preserve it. Static views of the 3D model can furthermore serve as illustrations in publications (Figs. 2, 3).

## 4.2 Research

As far as scientific research is concerned, the most obvious benefit of the 3D model is the fact that we can carry our study area with us. Although the fieldwork at Palpa has largely been concluded, the model enables us to easily go back to our virtual area of investigation whenever we need to review certain details of the geoglyphs. In archaeological research this is still a relatively new facility that makes analysis back home in the office considerably easier. Although the 3D model contains only a small fraction of the information available in the field, the accurate DTM and the high-resolution orthomosaic already reveal many helpful details.

The Palpa 3D model is the basic element of the GIS that we are currently establishing in order to analyze the manifold relations between the geoglyphs and the surrounding landscape (Grün, Sauerbier, Lambers, *in press*). The basic premise here is that the geoglyphs, located in a inhospitable desert that was altered on a large scale according to the concepts and needs of Nasca society, reflect some of these concepts and ideas, much like other archaeological artifacts reflect other aspects of Nasca culture. An analysis of the way the geoglyphs were designed, situated, made, and used therefore allows a better understanding of Nasca cultural concepts. Thus, the 3D model is a valuable tool for archaeological research. Basically, we plan to investigate the topography, the visibility, and the accessibility of the geoglyph sites, but there are many more interesting aspects. All these investigations have in common that a highly accurate 3D model is needed to ensure reliable results.

When analyzing the geoglyph sites in their surroundings, the first important topic is topography. During fieldwork we observed that certain types of geoglyphs seem to occur exclusively on certain types of terrain, e.g. anthropomorphic figures only on slopes, zigzag lines only on plateaus etc., but this observation has still to be verified. Furthermore, while most straight lines on inclined terrain are adapted to the orientation of the slopes, some lines clearly crosscut these given directions. It seems that some geoglyphs are adapted to the shape of the landscape, while others do not respect it. To analyze this topic systematically, archaeologically defined types of geoglyphs have to be mapped against types of terrain which in turn have to be defined – e.g., via the calculation of slope degree – on the base of an accurate 3D model.

If such relations can be ascertained, the next step is to explain them. For example, lines on plateaus could have been made to be walked upon, while figures on slopes could have been made to be seen from far away. This brings up the topic of visibility. It is a modern myth frequently repeated in the literature on the Nasca Lines that the geoglyphs can only be seen from above. At least in the Palpa area, each and every geoglyph is also visible

on the ground, though today it is allowedly often difficult to find them in the field and then to appreciate their overall form, size, and context. Still, the geoglyphs were made by and for the Nasca people who lived on the ground, and hence they were seen and perceived from a ground perspective (Aveni, 1990). This ground perspective changes when moving through the terrain, and with it changes the impression one gets of the geoglyphs. From the valley margins where most Nasca settlements were located, or from the irrigated fields on the valley floors that formed the economic base of Nasca society, only certain figures, lines, and small trapezoids are discernable. When climbing up to the plateaus, most of these geoglyphs disappear from sight, while long lines and large trapezoids on the high, flat terrain become visible, but usually only small parts of them. But the terrain in Palpa, with its ridges and mountains, offers certain points from which geoglyph concentrations can be seen in their entirety. And the excavations conducted on geoglyph sites revealed another important point: on several geoglyphs the remains of wooden posts were found deeply embedded into the ground at the narrow end of several trapezoids (Reindel, Isla, Lambers, 2002). These posts were probably up to 3 or 4 meters high above ground and thus added a strong vertical component to the geoglyphs, which today seem totally ground-bound. The posts must have been visible over long distances and could well have marked geoglyphs which otherwise would have remained invisible from far away. Using the Skyline software, simulated posts can easily be placed into our 3D model according to the excavation results. A systematic investigation of lines of sight and viewsheds, considering not only the geoglyphs but also the posts, will certainly yield interesting results. For example, certain viewpoints may be identified from which many geoglyph sites were visible. Or it may result that specific types of geoglyphs are especially exposed to sight, while others remain virtually hidden. These results in turn have to be explained considering what is known from other sources about the function of the geoglyphs (e.g. ceramics and stone structures; Reindel, Grün, Lambers *in press*). It is obvious that only a highly accurate 3D model can be used for such an investigation, because any height deviation would alter the results considerably.

Another important topic is the accessibility of geoglyph sites. Contemporaneous settlements and geoglyphs are situated in different settings: the settlements mainly along the valley margins, the geoglyphs mostly on the plateaus above the valley (Reindel, Isla, Koschmieder, 1999). The question is whether there is a recurring pattern in the spatial distribution of geoglyph sites and settlements from the same time period. In other words: Do certain geoglyph sites belong to certain settlements? This seems conceivable since at two of our excavation sites, geoglyphs formed integrated parts of the settlements (Reindel, Isla, 2001). But for the large geoglyph concentrations on the plateaus there are no obvious relations to settlements, most of all in the case of the complex sites in the dry valleys far removed from the settlement zones. By using the 3D model for the calculation of least cost pathways between settlements and geoglyph sites, it can be determined if there is a recurrent relation between both kind of sites. It is clear that due to the rugged terrain with many steep or sandy slopes, the shortest line between two sites is not always the fastest way.

Further uses of the 3D model for analyses mainly encompass investigations by our cooperation partners. The archaeologists plan to include the data from their settlement survey into the GIS and conduct a settlement pattern study using all the possibilities GIS has to offer in this field (Wheatley, Gillings, 2002). A group of geologists, hydrologists and geographers who are currently investigating the landscape genesis, paleoecology,

and climatic history of the Nasca region want to use the 3D model for geomorphological simulations. Thus, the use of the model for scientific research is manifold, and many important insights would not be achievable without it.

## 5. CONCLUSIONS AND FUTURE WORK

The 3D model of the Nasca Lines at Palpa (Peru) is the result of a joint long-term effort of geodesists and archaeologists. It has been shown that the model is designed to serve as a powerful tool for scientific research. Its real time visualization requires high end software like Terra Explorer Pro by Skyline. The integration of the 3D model on a GIS platform, the generation of meaningful archaeological objects on the base of mere geometric vectors, the definition of the data model for the GIS, and finally the analyses themselves are the next important steps. Another intended task is the analysis of a series of aerial images (B/W, scale 1 : 10'000) of the Pampa de Nasca, a vast plateau south of Palpa where the most famous geoglyphs are found. These images were also taken in 1998 but have not been analyzed yet. While in the case of the Palpa imagery an important part of image processing and analysis had to be done manually, for the Nasca images we aim at an automated aerotriangulation and DTM generation in order to make the workflow more efficient. Tests using a recent version of the Virtuozo NT photogrammetric software system (Supresoft Inc.) will show if for the poorly textured images of this arid region reliable results of automated aerotriangulation and DTM measurement can be achieved.

## ACKNOWLEDGEMENTS

We are grateful for the generous financial support granted by the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (SLSA, Zurich/Vaduz), the Swiss Federal Institute of Technology (ETH Zurich), and the German Archaeological Institute (DAI, Berlin).

## REFERENCES

- Aveni, A. (ed.), 1990: The Lines of Nazca. American Philosophical Society, Philadelphia.
- Grün, A., Bär, S., Bühner, T., 2000: DTMs derived automatically from DSPs - where do we stand? *Geoinformatics*, 3/5, pp. 36-39.
- Grün, A., Beutner, S., 2001: The geoglyphs of San Ignacio - new results from the Nasca Project. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Ayutthaya, Thailand, Vol. XXXIV, Part 5/W1, pp. 18-24.
- Grün, A., Brossard, J.-C., 1998: Photogrammetrische Kampagne Nasca/Palpa 1997. *SLSA Jahresbericht*, 1997, pp. 163-168.
- Grün, A., Lambers, K., *in press*: The geoglyphs of Nasca: 3-D recording and analysis with modern digital technologies. Paper presented at the XIV<sup>th</sup> UISPP Congress, Liège, Belgium, 2.-8.9.2001. Congress proceedings to be published in BAR International Series by Archaeopress, Oxford.
- Grün, A., Sauerbier, M., Lambers, K., *in press*: Visualisation and GIS-based analysis of the Nasca geoglyphs. Paper presented at the CAA Conference, Heraklion, Greece, 2.-6.4.2002. Conference proceedings to be published by the Hellenic Ministry of Culture, Archive of Monuments and Publications, Athens.
- Grün, A., Zhang, L., 2002: Automatic DTM generation from Three-Line-Scanner (TLS) images. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Graz, Austria, Vol. XXXIV, Part 3A, pp. 131-137.
- Reindel, M., Isla, J., 2001: Los Molinos und La Muña. Zwei Siedlungszentren der Nasca-Kultur in Palpa, Südperu / Los Molinos y La Muña. Dos centros administrativos de la cultura Nasca en Palpa, costa sur del Perú. *Beiträge zur Allgemeinen und Vergleichenden Archäologie*, 21, pp. 241-319.
- Reindel, M., Isla, J., Grün, A., Lambers, K., 2001: Neue Erkenntnisse zu Siedlungen, Bodenzeichnungen und Kultplätzen in Palpa, Süd-Peru: Ergebnisse der Feldkampagne 2000 des Archäologischen Projektes Nasca-Palpa. *SLSA Jahresbericht*, 2000, pp. 81-104.
- Reindel, M., Isla, J., Koschmieder, K., 1999: Vorspanische Siedlungen und Bodenzeichnungen in Palpa, Südperu / Asentamientos prehispánicos y geoglifos en Palpa, costa sur del Perú. *Beiträge zur Allgemeinen und Vergleichenden Archäologie*, 19, pp. 313-381.
- Reindel, M., Isla, J., Lambers, K., 2002: Abschliessende Untersuchungen zu Geoglyphen und Siedlungen in Palpa, Südperu: Ergebnisse der Feldkampagne 2001 des Archäologischen Projektes Nasca-Palpa. *SLSA Jahresbericht*, 2001, pp. 37-54.
- Reindel, M., Lambers, K., Grün, A., *in press*: Photogrammetrische Dokumentation und archäologische Analyse der vorspanischen Bodenzeichnungen von Palpa, Südperu / Documentación fotogramétrica y análisis arqueológico de los geoglifos prehispánicos de Palpa, costa sur del Perú. To be published in *Beiträge zur Allgemeinen und Vergleichenden Archäologie*, 23.
- Rickenbach, J. (ed.) 1999: Nasca – Geheimnisvolle Zeichen im alten Peru. Exhibition catalogue, Museum Rietberg, Zürich.
- Sauerbier, M., Lambers, K., *forthcoming*: From vectors to objects: modeling the Nasca Lines at Palpa, Peru. To be presented at the CAA Conference, Vienna, Austria, 8.-12.4.2003.
- Silverman, H., Proulx, D., 2002: The Nasca. Blackwell, Oxford.
- Skyline Software Systems Inc., 2001: Terra Builder Release 1.5.14 User Manual. <http://www.skylinesoft.com> (accessed 31.1.2003).
- Wheatley, D., Gillings, M., 2002: Spatial technology and archaeology: the archaeological applications of GIS. Taylor & Francis, London.