

„Mountains from Space“ – a Book Based on Remote Sensing Data for Supporting Public Understanding of Science

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Abstract

The cartographic depiction of high mountain areas has always been a challenge to generations of cartographers, surveyors and geographers. The maps resulting from this work contain a wide range of information, which are difficult to understand for a non-expert community. Hence the fascination of high mountain areas was up to now mostly reserved to experts and climbers.

New techniques in Computer based visualization and especially the possibility to generate virtual landscapes allow for a much more comprehensible and completely new perspective of mountain areas. The ease of access to high resolution digital elevation models and the vast availability of very detailed remote sensing data – like e.g. from the IKONOS-satellite – complement these techniques. This combination of data and technology gives the cartographer and geographer a comprehensive tool for generating high quality images of mountains.

Motivated by its work of the past years and recent developments in visualization the German Remote Sensing Center initiated a new approach to unveil the beauty of high mountains all over the world. Specialists in remote sensing technology and the earth sciences together with some of the worlds most reputed mountaineers – among them Reinhold Messner, Maurice Herzog, Sir Edmund Hillary and Stephan Venables – developed a concept for a book integrating different aspects of mountainous regions of the world. Targeted at the broader non-expert public a wide range of remote sensing material and computer based perspective views were generated and compiled in a high quality book titled “Mountains from space”. The core of the book is geographic content – illuminating history, geology, geomorphology, climatology and weather as well as many other phenomena concerning mountains. The over 150 large format colour views of mountains from space show the audience a wide variety of digital, satellite based maps not shown in this context before. In this paper the technology especially adapted for the generation of the maps will be discussed.

KEY WORDS: Mountains from Space, Scientific Visualization, Virtual Landscapes, Perspective view, Public Understanding of Science (PUSH)

1. Motivation

Only three percent of earth's surface show a height over 2000 meters and are therefore considered to be part of the High Mountains Regions. These regions are characterized by various, very diverse ecosystems and exceptionally active geo-physical processes (Veit 2004). Within relatively small areas extreme environmental conditions have led to highly specialized fauna and flora. Due to this extreme specialisation high-mountain-ecosystems react very sensitive to environmental change making them a kind of an "ecological, clinical thermometer" for global change (Glaser 2005). Monitoring these early-warning system with support of modern remote-sensing technology provides early indicators for instance for the development of the earth's climate. This way, even remotest regions can be observed on a regular basis showing apparent traces of the global warming effect. Apart from this indicator function and the enormous biodiversity these areas show millions of years of earth history and force of nature in the shear and crush zones of tectonic plates. Additionally monumental mountain areas always have been and still form the origin of numerous gotheads and mythical figures.

Today previously impenetrable areas are thoroughly explored, recorded and mapped by airplane and satellite based remote sensing techniques and barley a summit was not already conquered afoot by mountaineers or scientists. Additionally the possibility to traverse formerly insurmountable mountains at 11.000 meters in comfortable airplanes took some of the superficial fascination of the impressive world of high mountains. At the same time the very same technologies provide new stunning insights into this world and delivers the basis for new findings and scientific knowledge.

In 2004, science encountered mountaineering enthusiasm, when extreme mountaineer Reinhold Messner met scientists of the German Aerospace Center and the University of Freiburg. An idea was born - a book, illuminat-

ing the fascinating world of mountains in pictures taken by satellites and generated in computers combined with scientific knowledge and mountaineering experiences. Designed to communicate the information to a broad lay public but also containing substantial facts. The resulting book encompasses geographical, geological, climatic, ecological and historic contributions as well as mountaineering-related articles and should sensitize the reader to this very particular habitat.

A new visual concept was needed for the communication of the above mentioned topics, visually attractive and informative in equal measure (cp. Dibiasi 1990; Meisner 2000). The nearly exclusive usage of space based images and derivated perspective computer visualizations distinguishes this book clearly from the mass of current mountaineering literature and - following the idea of "Public Understanding of Science" - it is addressing a new and broader target group.

2. A new book concept

Perspective representations have been used over centuries and can not be considered as a new illustration concept. Even bird-eye views of landscapes have been known since the Renaissance. While modern cartography is using techniques such as isolines and hatching for a more and more accurate description of topographic features with two-dimensional maps, the strength of perspective views was and still is the more intuitive and emotional way to convey the impression of a landscape. This strength has been used already three hundred years ago by landscape architects promoting their projects. Today sketched perspective illustrations as they are mostly found in skiing areas and natural parks provide only a rough orientation and are often distorted and hand coloured as well as focussed on certain contents. While the decoding of topographic maps must be learned and requires a cognitive effort, three-dimensional representations based on real

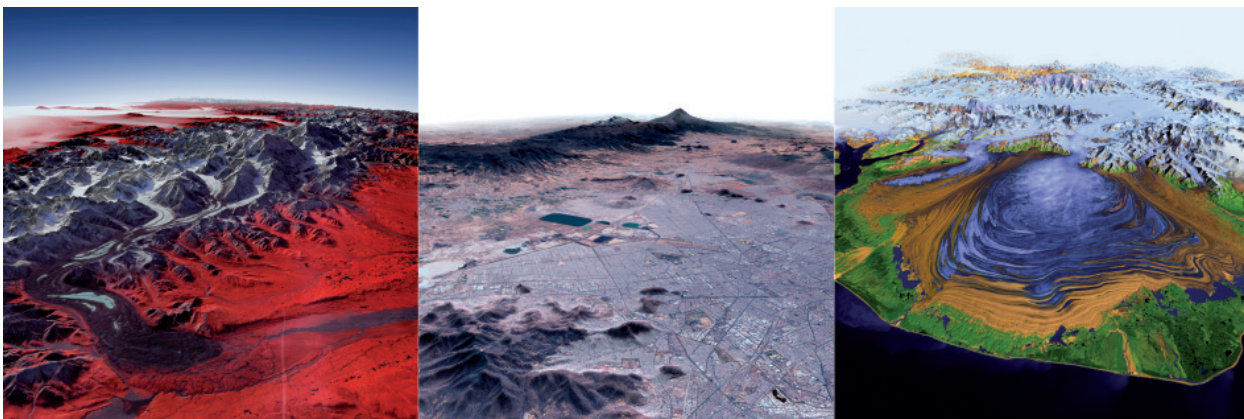


Figure 1: Left: The Denali (Mt. McKinley) covered in IR colours. Middle: Mexico City and the volcano Popocatepetl in true colors; Right: The Malaspina Glacier, the colors are the result of a combination of six spectral bands.

data are immediately understood because they are imitating the world the human sense is used to (Thompson and Horne 2006).

Rapid technical developments during the last years in the field of computer visualization and remote sensing now provide innovative techniques to generate three-dimensional views of landscapes based on highly accurate satellite data. This allows for a combination of scientific accurateness with intuitive and emotional reading. The ease of access to global satellite and elevation data allows for vivid and accurate visualizations even of the remotest regions on earth. The free selection of the view point and viewing direction enables the data user to choose the way an area should be displayed and which content should be highlighted. Scale is not so much of an issue as continental views can be realized as easy as detailed views of summits without running into common problems of generalization and still being accurate. Techniques used by painters of panoramic illustrations – such as selective exaggerations of important topographic features – have been abandoned completely for the book “Mountains from space”. Only the point of view, the parameter of the virtual camera, the illumination and different channel-combinations of satellite data have been used to create the intended suspense in the images.

The resulting authenticity in combination with previously unknown perspectives, unfamiliar channel combinations and a high optical quality largely contributes to the fascination of the views in „Mountains from space“. Together with images of diverse satellite sensors and photographs taken from the space shuttle, a new visual concept was generated suited as an attractive framework for the impartment of knowledge concerning the world of mountains.

3. Data research

A view years ago a book like „Mountains from space“ would barely have been thinkable in its current form.

Thanks to the enormous progress in the development of new satellite sensors and remote sensing technologies in recent years high resolution earth observation data is available even from remote regions. Only this data base and the ease of access via online catalogues and data banks made the compilation of the book possible.

For the book “Mountains from Space” over 4000 images have been sifted. Approximately 2000 Landsat images, 200 Ikonos images and 100 Quickbird images have been browsed in search for suitable material for the generation of perspective views as well as 1700 space shuttle photographs for further illustrations. Thousands of images have been selected in the first instance, transferred and catalogued in an image data bank especially set up for

this purpose. Additionally 300 datasets of the Shuttle Radar Topography Mission (SRTM) and further digital elevation models (DEMs) of other sources - such as GTOPO-30, ETOPO-2 or the national elevation dataset of the National Geophysical Data Center (NGDC) - were tested for their usability. All in all it took six month to research, review and catalogue over 140 Gigabyte of remote sensing data for the project. The work finally resulted in 148 high quality images. The search and selection was led by the intention to document the worldwide most important high mountain areas, considering not only the mountaineer's point of view but regarding also geographical, geological, ecological, historical and mythological aspects as well as data availability and quality.

All data and images were provided for free by the involved organisations and companies. “Mountains from Space” would not have been possible without support from commercial data providers, access to the National Remote Sensing Data Library of the German Remote Sensing Center (DFD) and further online libraries e.g. provided by the University of Maryland and the US Geological Survey.

3.1. Digital Elevation Models

The quality of the available digital elevation models (DEM) is crucial for the visualisation of high mountain regions. Whereas in smooth areas the poor quality of an elevation model can be compensated by using very high resolution images as a texture, the incongruity of DEM and texture is clearly visible in regions with high relief energy. Until 2004 only a very rough global elevation model existed. Providing a resolution of 30 arcseconds – about one kilometer at the equator – it allows only for overviews of complete continents. For closer maps - for example the depiction of single summits or even mountain ranges like the Alps – coarse elevation models are not usable as too many summits and details would be lost due to the low resolution of one kilometre per pixel.

In early 2004, after four years of intensive processing, a new global digital elevation model supplemented the one kilometer model available until then. A much higher resolution of 25 meter was rendered possible by the data of the Shuttle Radar Topography Mission of the year 2000. The SRTM model is globally available for free download with a reduced resolution of ninety meters whereas access to the 25 meter data is limited. The mission was equipped with a second radar antenna, which was operated by the German Aerospace Center and provides high resolution elevation data for certain regions. Wherever possible this data has been used for image generation for the book. Further elevation and bathymetry models were sporadically used for

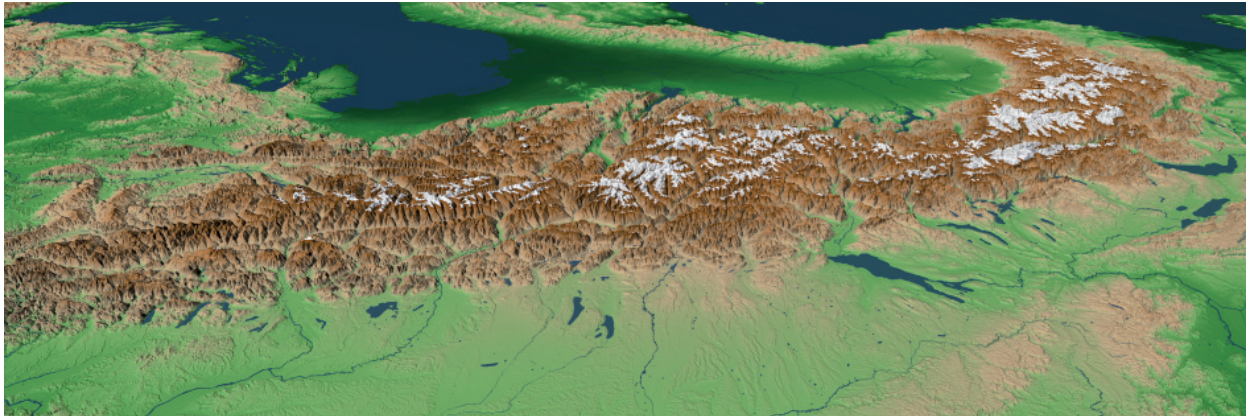


Figure 2: Virtual Alpine Panorama. A pseudocolored digital elevation model of the Alps seen from north to south.

example for the computer rendered visions of the Mount Everest and the panoramic view of Hawaii (Fig. 4, l).

3.2. Optical satellite data

For the colouring or so called texturing of the virtual landscapes mostly satellite images were used.

The satellite image availability proved to be excellent in the archive of the German Aerospace Center and other remote sensing data bases worldwide. Satellite images used range from high resolution images of Ikonos and Quickbird to Landsat and Spot scenes as well as medium resolution MODIS data. Due to American tax policy (tax financed data is free of charge) Landsat data can be downloaded easily from different servers. The University of Maryland provides a server containing – among others - global Landsat data sets. A large portion of the computer visualizations were realized based on this data. The resolution of up to 15 meters is perfectly suited for large overviews of mountain ranges, where – thanks to the lack of atmosphere in the virtual computer model – extreme clear views from unusual heights can be realised. Furthermore, the multispectral Landsat data was used to confront the beholder with unexpected, spectacular colourings typically used for scientific image analysis and better detail resolution (Meisner 2000) (Fig. 3).

Data from high-resolution satellites like Quickbird and

Ikonos was nearly unexceptionally used for bird-eye views only. Too obvious was the resolution difference between the high-resolution images and the used SRTM elevation model. Only for the visualization of Cape town these data sets could be combined thanks to a relative smooth relief.

Procedural textures were only chosen for the illustration of tectonic processes. Using an adapted atlas-like colouring of the heights, relief and bathymetry becomes much more apparent. Deliberately no consistent height colouring was used in favour of a better view of details. Also snow lines have been used primarily from an aesthetic point of view for the enhancement of the contrast within mountainous regions (Fig. 2, Fig. 5).

4. Geo-visualization

Not only the data, also adequate hard- and software would not have been available a few years ago. Even today, despite enormous graphical capacities of current computers, processing and visualisation of geo-data for high quality representations is still highly demanding. Especially the rendering of print-material requires very good resolutions and therefore high quality data and high computing capacities (Meisner et al. 1998).

Even specialised GIS and remote sensing software often fails when it comes to the visualisation of large, detailed landscape models. Furthermore the visualization capaci-

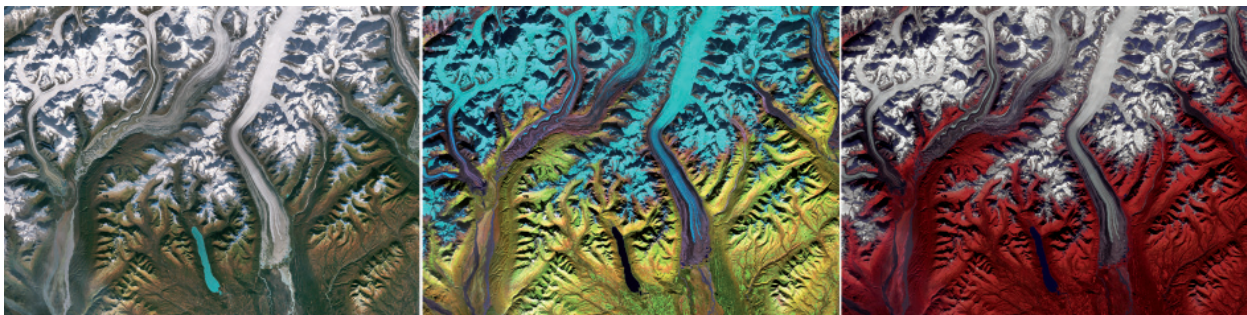


Figure 3: The Denali (Mt. McKinley) in various band combinations: 321 (RGB), 742 (IR, IR,G), 432 (IR,R,G).

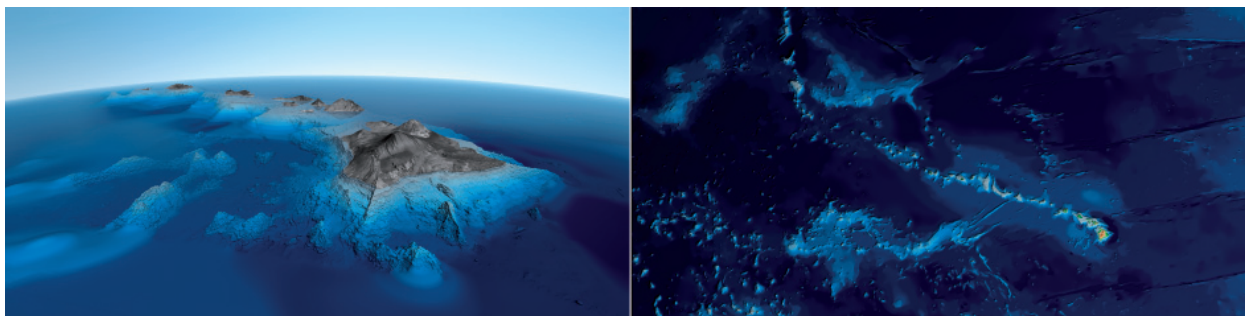


Figure 4: Hawaii, the highest mountain on earth. Left: The Hawaiian Islands in 3D with Mauna Kea seen from the ocean bottom to the top. Right: The Hawaii islands chain can be traced 2000 miles west, before it changes its direction to the north.

ties of this software packages are very limited in comparison to software used for professional 3D design and modelling. Visualization of geo-data is becoming more and more important, and the tools in traditional image processing and GIS tools are improving. But still these tools are barely suited for realistic, demanding landscape visualizations.

On the other hand, professional visualization tools used in the film, advertising and gaming industry can not handle geo-data at all. They do not provide the import of geo-referenced satellite or GIS data and handling of big elevation models is nearly impossible. Instead they offer sophisticated illumination, shadowing, texturing and a wide range of effects for the realistic rendering of objects.

Good landscape visualization needs both, geo-data support as well as realistic rendering. This demand is met by a small range of software solutions that specialised on the niche of geo-visualization. Only a few software companies and open-source initiatives serve this still young market. Their customers are mainly landscape architects and planning offices. The most capacious software in this field is presently Visual Nature Studio (VNS) of 3D Nature. VNS was used at the GeoVisualizationCenter of DFD for the generation of the three-dimensional perspectives in “Mountains from space”. The software combines the import of geo-data in various formats and geographic projections with the possibilities of modern computer graphic. The rendering of oversized panoramas is possible as well as animations or the compilation of real-time sceneries. The possibilities are still limited by computing time and memory resources when extremely large elevation models should be visualized. Therefore an additional tool was developed with IDL (Interactive Data Language) for the handling of the vast amount of data and the time-saving rendering of the large panoramas and perspectives shown in the book. The tool allows for the utilization of level of details (LOD), a concept widely used in real-time applications (Blaschke et al. 2006). The IDL tool gives the possibility to directly generate proprietary VNS elevation tiles in different LOD-steps depending on distance and po-

sition to the virtual camera. Only by using level of details large panoramas such as the Alps or the continental views could be rendered within acceptable time spans.

Still the most crucial factor for the visual quality of the resulting image is the human factor. Depending on the structure of the topography, the existence of eye-catching landscape elements like streams or lakes, the kind of land coverage and the quality of the data, different measures are needed to get an appealing visualisation. A few examples will give insights into the creation process and the difficulties encountered.

4.1. Mount Everest

Extremely deep valleys and steep slopes characterise the “roof of the world”, the Himalaya, an area highly demanding when it comes to surveying and creation of maps and digital elevation models. Even space based methods for the generation of elevation models encounter problems measuring this extreme relief. The first attempt to visualize Mount Everest was based on a digital elevation model derived from data of the Modular Optoelectronic Multi-Spectral Scanner MOMS-02. This camera developed by DLR provided elevation models with a resolution of 15 meters and was mounted on the Russian Space Station MIR until its end in 2001. The derived elevation model proved to be too small to cover the complete Everest region and too inaccurate for close-up views. Due to extensive snow cover insufficient landmarks were available for stereoscopic processing of the data. The SRTM model shows holes where summits should be and could therefore not be used. These data holes exist where high mountains caused shadows in radar images used for the generation of elevation models. Within these shadow-areas no information exists, that could be used for the generation of elevation data. Various attempts to create a panorama using the one kilometer data have not been satisfying either. The resulting virtual copy had no resemblance to its original. Also interpolation algorithms or data fusion methods did not succeed.

Hence a book called “Mountains from Space” without

Mount Everest was not thinkable. So in this very case airborne data provided by Swissphoto was used and now shows the most accurate elevation data existing of the Everest region and enabled some very high resolution detail-images of the top of the world.

The already mentioned lack of data in very mountainous regions is not restricted to the Himalayas. But in most cases it was solved by an adapted point of view of the virtual camera hiding the data faults behind intact relief. The detailed representation of the complete Alps though was only made possible by usage of an alternative elevation model derived from radar images of the European Radar Satellite Tandem Mission. This tandem mission is based on two independent radar satellites (ERS 1 / 2) flying in formation but slightly different orbits. These orbits allowed for the recording of identical areas from different angles. The resulting image pairs could be used for the creation of elevation models. This method is called dual pass interferometry due to its non-synchronous data acquisition and comes up with more inaccuracies than the single-pass method of the SRTM Mission. But, thanks to a much longer mission period of several years countless new data takes can be used for the successive improvement and gap-filling of the resulting elevation model.

4.2. Denali

North America's tallest Peak, also called Mount McKinley, is among mountaineers considered to be one of the most demanding summits due to its extreme climatic conditions. Its far northern location makes it the coldest mountain on earth surrounded only by high-tundra vegetation. Using a Landsat-Image with a band combination that corresponds to the human visual sense, the vegetation appeared in nearly indistinguishable tones of brown and grey. With regard to the fact that the true-colour image gives neither enough contrast nor an appealing look, an alternative band combination was chosen. This so-called colour infrared band combination uses the near infrared, the red and the green band of the various spectral channels of Landsat-7. This combination is very sensitive against vegetation, shown in red colours and allows the viewer to see much more information of the vegetated areas than true-colour images might provide. Thus, especially this image of the Denali makes it possible to distinguish between two types of tundra: dark red indicates wet tundra with its high-tangle of birches and willows; bright red alpine tundra in drier areas, with vegetation only a few inches tall. Ice of the various glaciers appears bright white while moraine debris covering most of the Muldrow Glacier shows up dark. The beholder looks from a virtual height of 16 000 meters on the glacier streams. Simulated atmospheric effects accentuate the Alaska Range and create visual depth (Fig. 1, l).

4.3. Malaspina

The perspective view of the glacier Malaspina in the Gulf of Alaska impressively demonstrates the influence of the choice of position and lens parameters of the virtual camera on the message of an illustration. The aim was to visualise the enormous dimension of the glacier, which is one of the largest foreland glaciers on earth. To emphasise the expanse of 4000 square kilometers of the glacier tongue a camera height of 11 kilometers was chosen in combination with an extreme wide angle lens. Similar to the Denali image the true-colour Landsat image showed the same unappealing brownish colouring. Furthermore the ice shield was oversaturated and showed no detail at all. Hence a sophisticated six-band combination was used, showing the Malaspina Glacier in very uncommon eye-catching colours. For areas without ice the combination of two infrared bands (the middle infrared and the near infrared) and the red channel was used giving more contrast and allowing the distinction of green vegetation. The terminal moraine appears in brown at the edge of the ice while the summer vegetation on the coastal strip is shown in green. Another combination of two bands in the middle infrared spectrum normally allows the distinguishing of different soil types. In this case it was used to differentiate the ice cap of the Glacier due to the sensitivity of infrared bands to water content and ice. Open ice appears in blue while snow cover on the Elias Mountains is shown in white (Fig. 1, r).

4.4. Hawaii

The island of Hawaii is commonly not considered as a mountaineering highlight due to the fact that its mountain-related qualities are well hidden below the sea surface. If one includes Hawaii's vast submarine foundation, Mauna Kea (4205 meters) reaches a height of about 9700 meters, making it the world's tallest mountain.

The combination of precise remote sensing data from satellites and sonar ships with digital imaging technologies made it possible to reveal the concealed submarine slopes as well as showing the neighboring islands forming part of the volcanic chain that can be traced over 6000 kilometers up to the Russian mainland (Fig. 4, r).

The virtual camera was positioned in an altitude of 100 kilometers where the crescent-shaped horizon line is clearly visible. The high viewing point not only shows the youngest volcano, Mauna Kea, but also the older western volcanic islands already eroded and caved in due to the pressure of their own weight.

The different elevation and bathymetry models of various resolutions used for this image were seamlessly combined to one large elevation model. As overlay for the terrain a satellite image of Landsat 7 was used.

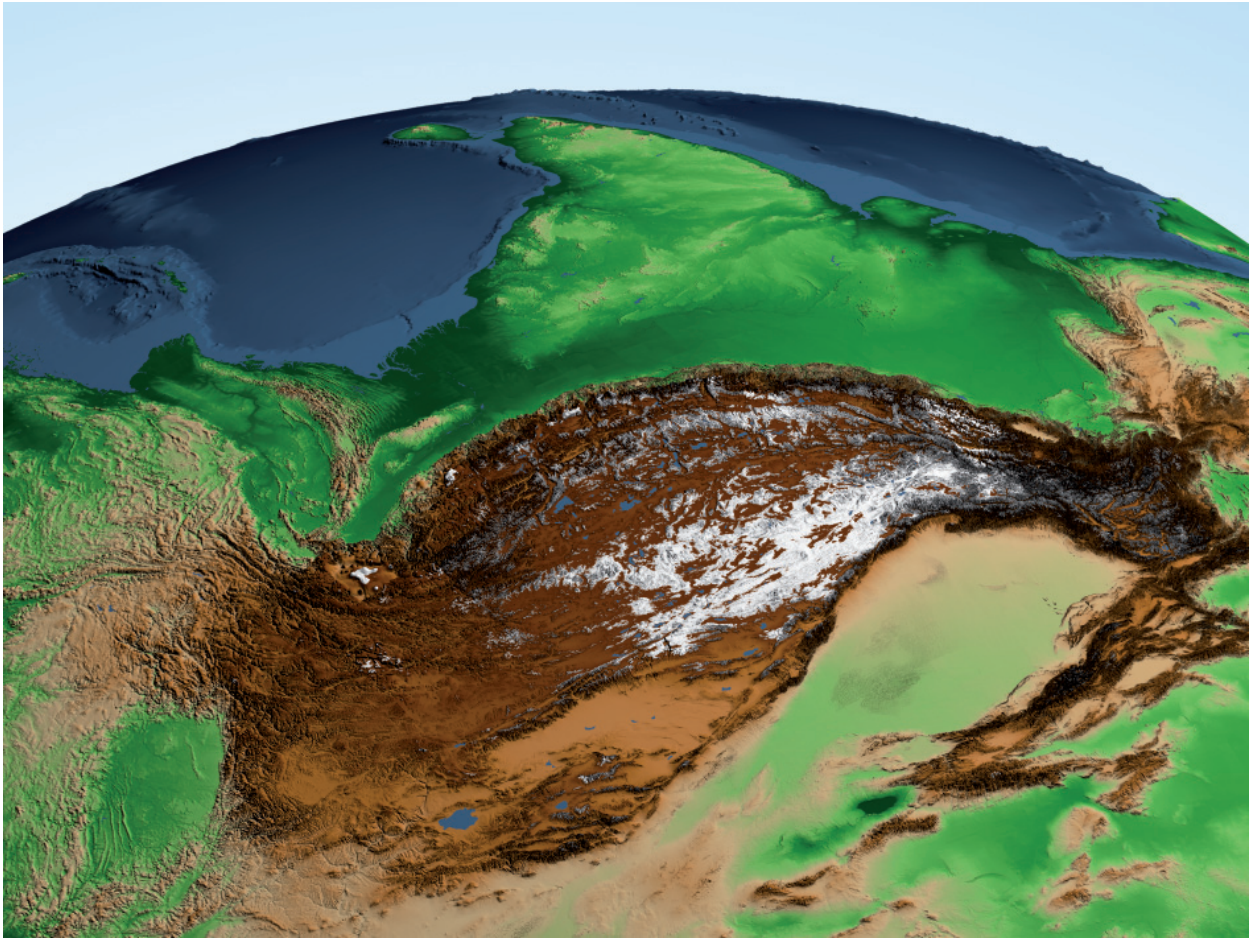


Figure 5: Virtual panorama of the Himalayas seen from north to south with the Indian sub-continent in the background. The coloring from green to yellow to brown corresponds to the altitude layers.

In the infrared image one can see a number of lava streams on the flanks of Mauna Kea that stand out as darker streaks. The single-band greyscale image overlay was chosen to accentuate the relief without drawing the attention away from Hawaii's vast submarine substructure which steep slopes are clearly visible through a semi-transparent water surface. On land relatively flat slopes were created by lava flowing out slowly, whereas the submarine slopes are showing steep, jagged rock formations caused by the rapid cooling of the lava in contact with water (Fig. 4, l).

The image of Hawaii won a first price in the Science and Engineering Visualization Challenge 2006 organized by the journal *Science* and the National Science Foundation.

5. Conclusion and future developments

The high-quality book "Mountains from Space" has been translated in various languages and over 70 000 copies have been sold since 2005 worldwide, a great success for a book in the upscale segment. Very positive press coverage and the excellent sales figures can be seen as evidence

that the book concept achieved its intended aim imparting scientific knowledge to a broad lay-public by usage of an attractive visual design.

The attraction and fascination of the synthetic enhancement of the human perspective by computer rendered visualizations took even hold of the extreme mountaineer Reinhold Messner. He says: "From a peak one enjoys an overview of the surrounding landscape, from space one can witness the evidence of millions of years of the earth's history. The processes of glaciation, eruption, sedimentation and erosion can be seen at work" [...] "Only from this great distance does the earth's crust appear viscous and malleable. Down here we are too close to see it as such" (Messner 2005).

This alien perspective was rendered possible only by modern remote sensing technologies. Drawing the attention of the general public to this important tool for the monitoring of our environment finally was the motivation of the German Aerospace Center to publish the book.

But this book also shows how close we got to the vision of a digital earth proclaimed in 1998 by American vice-

president Al Gore. Yet it is foreseeable that the quality of the perspective views in this book will soon be available interactively by tools like Google Earth (cp. Häberling and Bär 2006; Kraak 2006).

Also in the field of remote sensing further milestones are already anticipated in the very next future. The coming German radar satellite mission TerraSar X and the following Tandem Mission yet promise the global availability of elevation models with a resolution hundred and fifty times better than that of SRTM data.

High resolution data and new interactive visualization tools will presumably soon be widely used in public, commercial, scientific and private spheres establishing the usage of perspective views where until now only topographic maps can be used. The scientific visualization in the field of remote sensing will then need a new visual language to be successful in the media's stiff competition for the attention of the general public and to convey the uniqueness of this intriguing topic.

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Links:

Global Landcover Facility GLCF
<http://glcf.umiacs.umd.edu/index.shtml>

NGDC Coastal relief Model Vo. 10
<http://www.ngdc.noaa.gov/mgg/coastal/grddas10/grddas10.htm>

JSC Digital Image Collection
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USGS EROS Data Center
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Spaceimaging/GeoEye
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