The Coastlines of the World with Google Earth

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Understanding our Environment

Springer

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For Yanik and Emile

Foreword

Our living environment in all its grandeur, diversity and different scales from global to local can best be represented visually, as compared to any possible verbal descriptions. The coastlines of the world, with their total extent of at least one million kilometres, offer an excellent model for such a visualization. An overview must include the most important variations that occur in different latitudes, different geologic settings, through time and sea level changes or climatic parameters. Such detail can only be presented by the use of high resolution satellite images. Google Earth imagery mostly has such a resolution that allows visualization of individual features down to view altitudes of 500 m, which corresponds to a scale of approximately 1:5,000 or a resolution per pixel of less than 1 meter. Therefore, we chose to base this book mainly on Google Earth imagery (captured in 2010), thus showing the present day situation. Additionally, terrestrial photographs and some oblique aerial photographs taken during our various field campaigns along the coastlines of the world are added, in particular to show small features down to micro-scales and those which are hidden in vertical pictures such as steeper slopes or perpendicular cliffs. For many coastal features, information regarding their spatial extension is added in world distribution maps and more details are provided on graphs. The book shows and explains landforms and geomorphic features of different dimensions and as a result of different formational agents and processes (wind, waves, currents, tides, extreme wave events such as storms and tsunamis or by anthropogenic changes).

In our view, it is crucial for now 7 billion of us on the planet to become more knowledgeable (in contrast to being informed) about the parts and processes that currently interact on our home in the universe – planet Earth. Our ancestors have always been interested and concerned with the local weather, climate or water availability, but with the fast rate of environmental change on a global scale during the last hundred years it becomes more and more important to appreciate and understand the interconnections and interrelationships that govern Earth and create our living environment on a global scale. During the last decades, technical advances, increasing computing capacity and more sophisticated numerical modelling have transformed almost every scientific discipline into a highly complex and technical research area. Today, most scientists are specialists in one ever-narrowing research field, on the other hand the emerging science of the Earth System is changing the way scientists study Earth. With this more holistic view of the way our planet works, we want to engage, stimulate and motivate the individual person to undertake their own research and follow up with open questions in specialist texts – or even take up a career in some aspect of our Earth system.

Although this book tries to present coastal features from around the world, there are some restrictions: the low resolution or the lack of high quality pictures close to the polar regions (depending on the angle of the satellite tracks), and the difference in the spatial resolution of the images in different regions of the world, which vary from excellent (have a look at New York, where you can see single cars on the streets) to very poor, clouds may cover parts of an image, reflections from surface features (water), an unfortunate angle to the sun's rays – all these parameters may influence visibility and quality of the image data. However, Google Earth is constantly developing its set of images, and more areas will continue to appear on Google Earth's virtual globe with higher resolution in the future. Consequently, the difference in picture quality and the mosaics of different pictures from different years or with different light conditions is an obstacle in the interpretation of details. Therefore pictures of very large areas are not chosen for presentation in this book.

For this project, we would like to acknowledge the generosity of Google Earth to give permission to publish Google Earth imagery and express our thanks to Ed Parson who helped to make the book possible. As this is not a textbook for students, references are used only to acknowledge sources for material and figures, and by citing books and articles such as reviews or those presenting the state of the art for certain aspects of coastal sciences.

We gratefully acknowledge the assistance of Springer Publishing and in particular the enthusiastic support of Petra van Steenbergen, Editor of the Earth Sciences and Geography section, in preparing all parts of this book, as well as the generous support by Charles Finkl Jnr. from the Coastal Education and Research Foundation in Florida (USA) regarding copyrights of Publications in the Journal of Coastal Research. The design and layout of the book was created by Hans van der Baan and Ingeborg Scheffers in the Netherlands. Thanks to you the book is visually stunning and of high quality. Southern Cross University in Lismore (NSW, Australia) supported their work with a substantial fund based on their vision that it is vital for universities to engage with communities in ways beyond the usual academic halls. Gudrun Reichert, cartographer at the University of Duisburg-Essen (Germany) created most of the basic graphs and world maps, and Anne Hager (University of Duisburg-Essen, Germany) supported the book in many ways with her energy in problem solutions and we thank Kelly Fox (University of Queensland, Brisbane) for patience and input in text editing. We are very grateful to Bob and his passion for communicating geology. His guidance, grace and professional acumen made this book educationally sound. Finally, it should not go without saying that we are grateful to our families, our colleagues and our students at Southern Cross University (Australia) and the University of Cologne (Germany). We love working together – thank you!

Anja M. Scheffers *Sander R. Scheffers* *Dieter H. Kelletat*

About Google Earth

Virtual, web-based globes such as *Google Earth*, *NASA World Wind* or *Microsoft Virtual Earth* allow all of us to become travellers visiting the most remote places and tour our planet or even outer space at speeds faster than a rocket. Any computer user can easily, at no charge, download and use Google Earth (for both PC and Mac computers).

If you have not done so already, download *Google Earth,* version 6, from *earth.google.com,* install it on your computer, and prepare yourself to fly around the globe on your own research expedition (Fig. 1.1). You can travel to millions of locations and look for the context of all landscape features of interest to you (geography, geology, vegetation, man-made structures and more). You can also see these objects from different altitudes (i.e. in different scales), perspectives and directions; you can view a chosen area around 360° from an imaginary point in the air; and you can fly deep into canyons and craters. You can look straight down in a traditional 2D perspective or enable an oblique view in 3D, you can hover above one location, circle around or fly like a bird over countries, continents and oceans. In this book we focus on geologic and geographic features, but that is only a snapshot of what Google Earth is providing with their virtual globe. There is no room here for a complete tutorial, but you will find that the program is so easy to use and understand that you will be an expert after working with it for a few minutes. Please visit the Google Earth web page for a complete free Google Earth tutorial which is constantly updated to reflect the improvements in different versions of Google Earth (http://earth.google.com/support/bin/answer.py?hl=en&answer=176576).

We hope that the diversity of the coastlines of the world will come alive for you and stimulate your curiosity to become a coastal explorer of these fascinating places either as a hobby or profession.

Table of Contents

Introduction: Oceans and Coastlines

The most extended landforms on our planet are the coastlines; in natural scale certainly they are more than one million kilometres long. Along these vast boundaries between land and sea the variety and diversity of processes and forms leading to a coastal landscape we treasure today are immense. Some processes like the rising sea level after the melting of the large ice sheets from the last ice age are affecting coastlines globally, but some processes operate only in specific environments. Imagine for example the warm tropical waters of the lower latitudes where coral reef building organisms live and have created the largest geomorphological structure ever which can be even seen from space. These coastal environments differ completely from the ice and permafrost shaped coastlines of the Arctic regions. The coastal forms and processes we see today depend on the earlier geologic history, rock type, climatic province, sea level variations and the dynamic processes of the oceans such as waves, tides, or currents which themselves depend upon water depth, exposure, size of the ocean basin and many other factors. Coasts at the same time are regions with extreme morphological activity, comparable only with those of active plate boundaries where volcanism creates dramatic landforms or in regions where wind or ice and glaciers constantly form and sculpture the environment.

Along coastlines geology can be seen in action and you can observe forming and transforming processes even during a walk on the beach or surf in the waves. If you visit your favourite beach destination from year to year, you can trace the changes on an annual scale and often extreme events like storms change the coastline dramatically within a day or two creating new landforms or eroding large beach sections.

Whereas the surface forms under the oceans as well as those on land may be very old, from thousands of years up to tens of millions of years, all of the coastlines of the world are geologically young and represent only a tiny moment in Earth´s history, that will change dramatically in the next geological moment, and which were much different just a geologic moment ago. Sea level during the last Ice Age, about 23,000 to 18,000 years ago, was 120 m deeper than today. As the climate got warmer and the ice melted sea level reached its modern position not longer than 7,000 years ago and possibly as recently as about 6,000 years (Anthony, 2009; Bird & Schwartz, 2010; Carter, 1988; Davidson-Arnott, 2010, Kelletat, 1995; Schwartz, 2005; Woodroffe, 2003).

Scientists love to classify and categorize, seeing patterns and order in the complexity of our natural world. They invent taxonomies (Taxonomy is the art and science of classification) for plants, animals, bacteria or soils and coastal scientists are no different: They classify coastlines in attempts to characterize dominant features in terms of physical or biological properties, modes of evolution, or geographic occurrence: Is the coast advancing or retreating, emerging or submerging; do we see constructive or destructive processes operating; is the coastline rocky or sedimentary; tropical or extra-tropical; with or without sea ice; a shallow water coast or a deep water coast; exposed or sheltered; does it have high or low tide regime or it is exposed to high or low wave energy? – To give few examples!

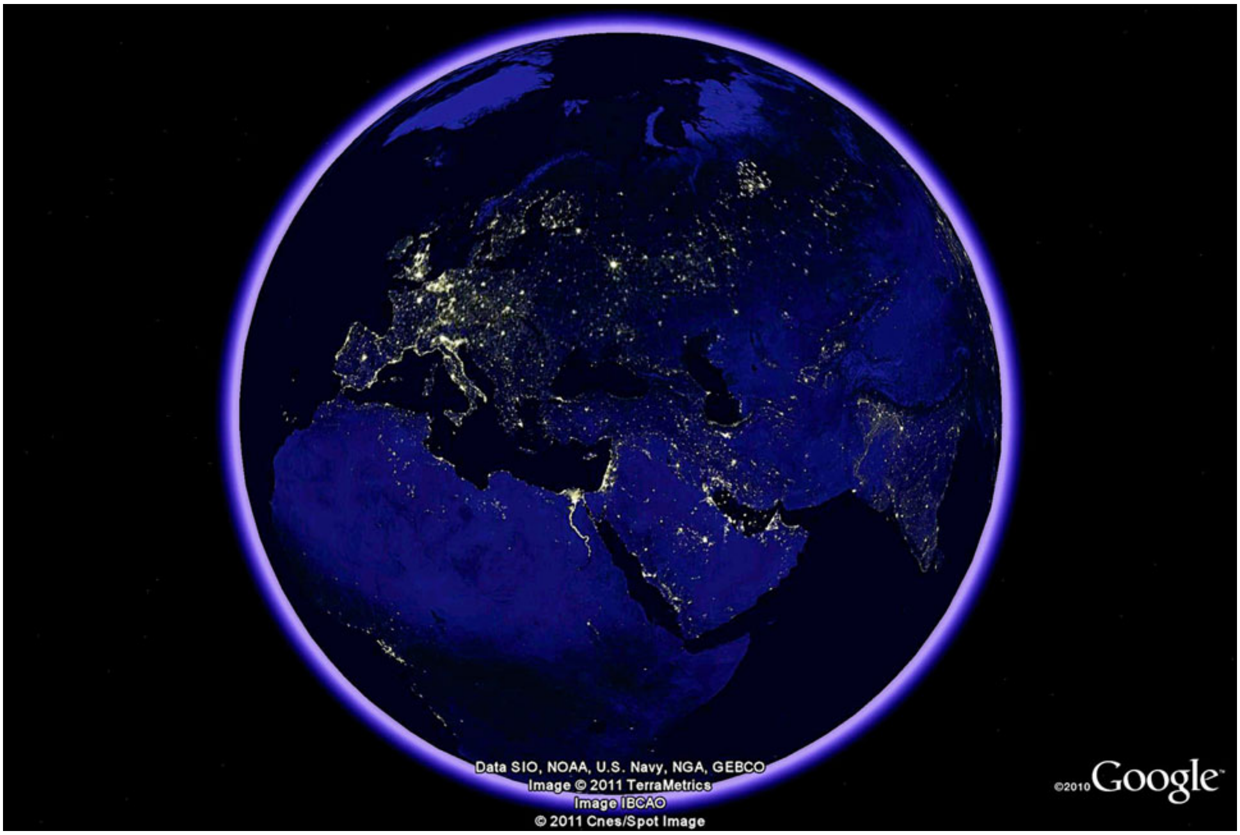

Fig. 1.1 Earth at Night (Credit: ©Google Earth). You'll find a Layers section in the sidebar. Expand the Gallery Content folder and the NASA subfolders. Then click on the small rectangles next to each option to enable it.

Another classification distinguishes between "*primary coasts*" and "*secondary coasts*". Primary coasts have preserved their initial form from terrestrial processes and now appear partly drowned by the postglacial sea-level rise. They do not show any significant transformation by coastal or marine processes since the last rise of sea level whereas the forms of secondary coasts reflect modern littoral/coastal/marine processes, mostly either by destruction (e.g. a cliff), or by construction (e.g. a beach, barrier or delta). In general, all terrestrial landforms – when partly submerged by the postglacial sea level rise – can appear as coastlines and give them their typical aspect, glacial roches moutonnés (as skerries), glacial valleys (as fjords), cone karst (as drowned karst towers), dunes and deflation depressions, river gorges (narrow rias) and many other forms. In the coastal classification system they have been given special names if they appear as coastal features.

Cities tend to grow along coastlines and transportation networks as you can see in the Night Earth view of Google Earth. Even without the underlying map, the outlines of many continents would still be visible (Fig. 1.1). They are the place where more than 45 per cent of the world's population lives and works and 75% of the mega-cities with populations over ten million are located in coastal zones. Thus, people, infrastructures and economics in coastal zones are potentially vulnerable to natural marine hazards such as storms or tsunamis as the devastating effects of Hurricane Katrina in US (2005), Cyclone Yasi (Australia, 2011), the Indian Ocean Tsunami 2004 or the powerful tsunami that hit Japan in March 2011 have shown.

Surprisingly, an unsolved question hitherto is: What is a coastline? There is no standard definition of what constitutes "the coast" because it depends largely on one's perspective or the scientific question – the coastal zone can be considered more the sea, or more the land. Imagine you have to draw the coastline of your favourite holiday destination on a map with a scale of 1:100,000. This will be easy, if there are perpendicular cliffs, but in all other cases it is difficult and needs some convention for comparison and overlap to neighbouring maps. In particular along flat depositional shorelines with high tides and storm wave impacts the actual shoreline or limit between water and land may shift for many kilometres or even tens of kilometres horizontally, at some places twice a day! If the detail of our maps is large enough (e.g. 1:10,000 to about 1:100,000), a low water coastline (MLW = mean low water) and a high water coastline (MHW = mean high water) can be differentiated, but with less detail this mostly is impossible. We can also argue that the definite limit between land and sea is along a line where sea water will never reach, but this may be far inland from the mean high water level and will differ from place to place significantly. Nevertheless these are important legal aspects, for coastal management or risk protection measures from the sea. In the following sub-chapters we will briefly present processes from the hydrosphere (the oceans), which influences the formation of coast, including organisms.

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