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Optimisation of global grids for high-resolution remote sensing data

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ABSTRACT

Upcoming remote sensing systems onboard satellites will generate unprecedented volumes of spatial data, hence challenging processing facilities in terms of storage and processing capacities. Thus, an efficient handling of remote sensing data is of vital importance, demanding a well-suited definition of spatial grids for the data's storage and manipulation. For high-resolution image data, regular grids defined by map projections have been identified as practicable, cognisant of their drawbacks due to geometric distortions. To this end, we defined a new metric named grid oversampling factor (GOF) that estimates local data oversampling appearing during projection of generic satellite images to a regular raster grid. Based on common map projections, we defined sets of spatial grids optimised to minimise data oversampling. Moreover, they ensure that data undersampling cannot occur at any location. From the resulting GOF-values we concluded that equidistant projections are most suitable, with a global mean oversampling of 2% when using a system of seven continental grids (introduced under the name Equi7 Grid). Opposed to previous studies that suggested equal-area projections, we recommend the Plate Carrée, the Equidistant Conic and the Equidistant Azimuthal projection for global, hemispherical and continental grids, respectively.

1. Introduction

High speed internet, enhanced sensor systems and cost-efficient data storage allow vast amounts of data to be generated in various fields of science and technology. Moore's law is no longer valid – data volumes are scaling faster than computer resources (Bierig et al., 2013). Accordingly, in the field of earth observation, a new generation of spaceborne high-resolution imaging sensors is emerging. They will produce unprecedented data volumes and consequently challenge up-taking facilities in terms of storage and processing capacities. For instance, the upcoming European satellite missions Sentinel-1 and Sentinel-2 will generate radar and optical raw images, respectively, of 640 TB (Hornacek et al., 2012) and 580 TB (Drusch et al., 2012) per annum.

Remote sensing observations deliver information on the Earth's features and conditions in digital form and thus are often represented by discrete raster systems. These so-called grids reference the individual observations to geolocations. The efficient and accurate handling of remote sensing data is dependent on the grid being used. Motivated by the vast amounts of data that will be generated by upcoming Earth observation missions, our research aimed for identifying an optimal definition of global grids for high resolution satellite data over land.

A key feature of satellite missions for Earth monitoring is the long-term record of data time series, built of alone-standing images. Thus, in remote sensing and in the global scope, the mosaicking of individual satellite images to a common data space facilitates generation and analysis of temporal products.

Finally, the sought grid system should facilitate efficient data storage as well as accurate spatial and temporal manipulation of the data for processing higher level products. Ideally, archiving, processing and display of the data are carried out in the same grid system, so that products of different levels are easily related.

1.1. Raster grids

Spatial grids define a set of geodetic locations and form a reference for storage, manipulation and display of spatial data. In general, there are two types of grids: Irregular grids define each location explicitly (through functions or lookup-tables), whereas regular grids define each location implicitly with a fixed sampling distance relative to a set of linear axis; commonly two orthogonal ones. A detailed overview on grid definitions is given by Sahr et al. (2003), focusing on the potential of irregular grids.

The studies of Hortal and Simmons (1991), Seong (2005b), Sun et al. (2007) and Birch et al. (2007) represent a rich variety of

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irregular grid definitions for spatial data. Data stored in such grids suffers limited shape distortion, information redundancy and data loss since the grid locations are defined in a mesh on a three-dimensional model of the Earth. However, global datasets with high spatial resolution comprise an immense number of discrete locations. The individual identification of locations in an irregular grid can be computationally demanding, requiring specific algorithms and lookup-tables.

Alternatively, regular grids can be used, bringing some advantages: (1) They address locations implicitly with a small set of parameters. An orthogonal grid – a Cartesian coordinate system grasped as an array – is directly indexed by computers and is thus expected to be more suitable for handling datasets with high resolution. (2) Neighbour relationships of measurements are evident from the indices, whereas irregular grids necessitate (costly) computation of those. (3) Image data are favourably manipulated and exchanged in the form of arrays. (4) Remote sensing software functions often use arrays as input and output, requiring data stored in irregular grids to be transformed into a two dimensional representation. Such transformation is not required in the case of regular grids. (5) Similarly, also the display of data on screen or in print impose a two dimensional representation.

However, regular grids have a major drawback since they do not allow a three-dimensional definition of locations in a convenient manner. In geometry, a regular grid is considered as a plane to which geographic locations are transformed by a map projection. The latter is a set of mathematical functions between the Earth's curved surface and the plane of the grid. Due to the fact that the Gaussian curvature of a plane is different from a sphere or ellipsoid, map projections, and therefore also regular grids, cannot represent the Earth's surface without distorting lengths, angles or areas (Feeman, 2002).

1.2. Regular grids – state of the art

Recognising the necessity of regular grids for the practicable and efficient handling of large remote sensing datasets, much research on shortcomings of map projections in respect to rasterised data has been carried out. It is almost consistently reported that (a) raster data should be treated differently than vector data, (b) a grid's accuracy and efficiency is bound to the distortions of the underlying map projection and (c) projections featuring true areal scale yield more favourable conditions than those with true angular directions.

Map distortions reduce accuracy and efficiency of a regular grid in form of pixel loss and duplication (Mulcahy, 2000; White, 2006). Those effects appear inevitably when transferring input datasets to raster databases, which is nothing other than resampling (Seong and Usery, 2001; Kimerling, 2002). In the literature, resampling is identified consensually as a source of errors and cause of unrecoverable loss of information and thus should be used as little as possible. Finn et al. (2012) discussed errors caused by spatial resampling and presented enhanced reprojection methods that pay particular attention to data at a global scale.

Steinwand et al. (1995) pioneered on this topic, introducing pixel distortion effects to the remote sensing community. They performed a window-based counting of resampling errors when transforming between different map projections. Similarly, Kimerling (2002) examined the loss and duplication of data when transforming from the conversant Plate Carrée (alias Equirectangular projection) to equal-area projections. Mulcahy (2000) developed two metrics called pixel loss and pixel duplication. She determined those for various global equal-area map projections and identified solely the Sinusoidal projection as optimal for raster images, effecting zero loss and duplication of pixels. Seong and Usery (2001) came to the same conclusion, using a theoretical approach based on vertical and horizontal scale factors. Further recommendation of equal-area projections and in particular the Sinusoidal for constructing global raster data grids is given by Seong et al. (2002), Seong (2005a) and Usery et al. (2003).

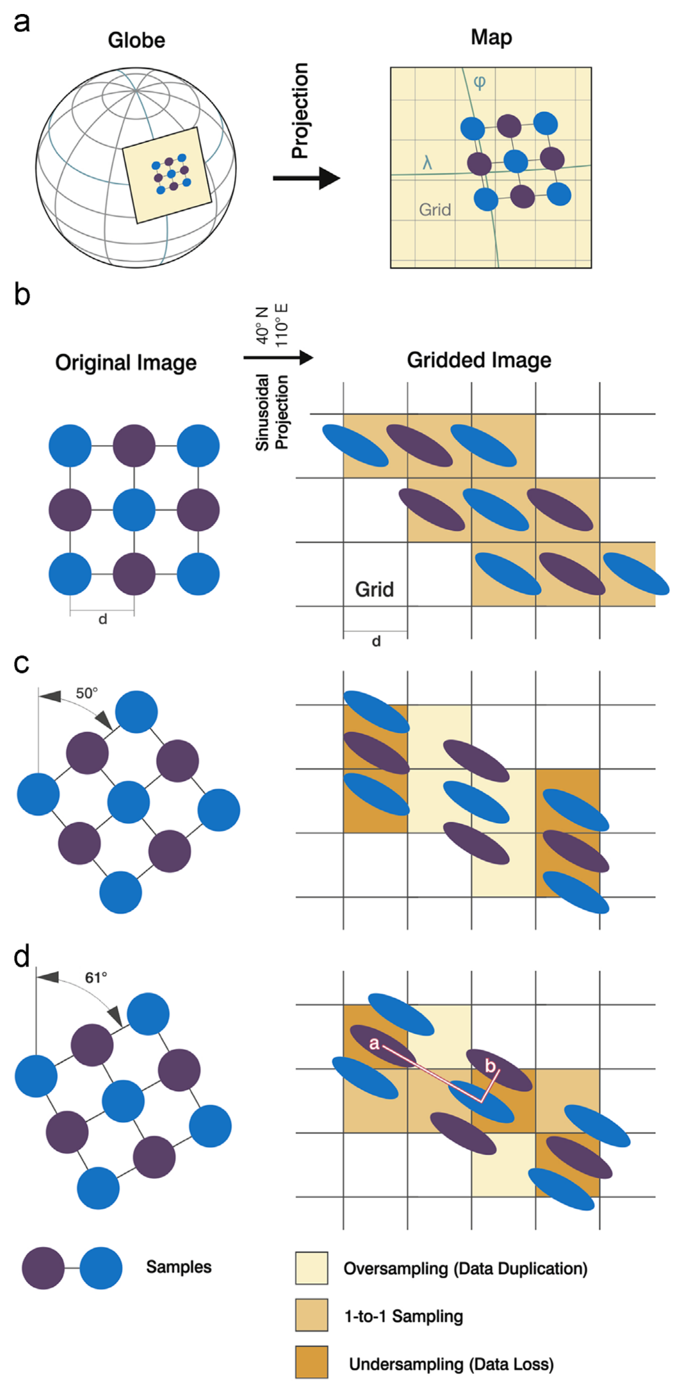

Fig. 1. (a) Illustration of mapping process using projections; on the left situation on the globe with the input image comprising individual measurements and on the right the projected image overlaid on a regular grid. (b)–(d) Effects resulting from the Sinusoidal's skewing and the orientation of input images. On the left input raster images and on the right their projected output raster representations overlaid on a regular grid with grid sampling distance *d* equal to the sampling distance of the input raster. Orange colours indicate data density for each output raster pixel. (b) Case of input image raster aligned with output grid raster. (c) Case of input image rotated by local skewing angle. (d) Case of input image aligned with directions of local extreme length distortions *a* and *b*. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)