Sunshading global datasets

G.R.J. Cooper*

School of Geosciences, University of the Witwatersrand, Private Bag 3, Johannesburg 2050, South Africa

Received 27 May 2004; received in revised form 15 October 2004; accepted 18 October 2004

Abstract

The proliferation of satellites in the last 30 years has resulted in a similar proliferation of global datasets, not only of the Earth but also of other bodies in the solar system. Measured parameters include topography, temperature, water vapour, electron temperature and density, and the strength of the gravity and magnetic fields, to mention just a few. Directional derivatives and sunshading are powerful tools for enhancing linear features in raster datasets. This paper demonstrates modified directional derivative and sunshading algorithms that take into account the curved geometry on the surface of the sphere, and hence are able to be used with global datasets (assuming the Earth or other body to be a sphere). The algorithms can either be used to enhance any linear features (i.e. great circles) than pass through a chosen point, or to attenuate them. They can also be used to enhance small circles of any radius centred on a given point, or to attenuate them. Source code, in Matlab format, is available from the IAMG server at www.iapg.org.

Keywords: Hill shading; Topography; Feature enhancement

1. Introduction

Satellites have been circling the globe since Sputnik 1 in 1957, and hundreds are now in operation, many of which make measurements of the surface of the Earth in different portions of the electromagnetic spectrum (e.g. Landsat or Spot), or use active techniques such as radar (e.g. Radarsat). Measurements of the strength of the geomagnetic field were made by Magsat in 1980. The recent space shuttle radar topography mission has produced a near-global set of topography data with 30 m horizontal resolution, and the Etopo30 dataset of the USGS has been available for some time. NASA probes have been recording similar datasets from other bodies of the solar system for over 30 years.

Two similar commonly used tools that are applied to small-scale datasets (i.e. those which cover a small area such that the surface of the Earth can be considered flat) are the directional derivative and sunshading. The directional derivative is just the gradient of the data f in a given direction \( \phi \), and can be computed as a weighted sum of the NS and EW gradients, i.e.

\[
\frac{\partial f}{\partial \phi} = \frac{\partial f}{\partial x} \cos \phi + \frac{\partial f}{\partial y} \sin \phi.
\]

Linear features oriented orthogonal to the filter azimuth will be enhanced as a result of the filter application, while those that lie parallel to it are reduced in amplitude.

Sunshading considers the data as if it were a topographic surface and illuminates it with light from a source at infinity which is specified by its azimuth and...
Different reflectance models are available for different types of surface (rough, wet, specular, etc.). A common reflectance model is the Lambertian reflector, where the reflectance is given by (Horn, 1982)

\[
R = \frac{1 + p_0 p + q_0 q}{\sqrt{1 + p_0^2 + q_0^2} + \sqrt{1 + p_0^2 + q_0^2}},
\]

(2)

where \( p_0 = -\cos \phi \tan \theta \), \( q_0 = -\sin \phi \tan \theta \), \( \theta \) is the sun elevation, and \( \phi \) is the azimuth. \( p \) and \( q \) are the EW and NS gradients of the data. Both the directional derivative and sunshading filters have seen common application to geoscientific datasets, and are implemented in most commercial image processing packages.

2. Enhancing global datasets

A great circle is the line of intersection of a sphere with a plane which passes through its centre (Ayres 1954, p.147). If the plane does not pass through the centre of the sphere then the line of intersection forms a small circle (Ayres 1954, p.147). The great circle connecting any two points is the shortest path between them, over the surface of the sphere. Hence, on the sphere linear features are great circles or portions thereof, and the problem of the enhancement of linear features becomes one of enhancing the great circles. The direction of the derivative (and similarly the sun azimuth) must be made to vary across the globe in such a manner as to remain orthogonal to a great circle situated 90° from a given sun position. Fig. 1 shows a spherical triangle that connects the sun position, the North pole of the sphere, and a point on the sphere’s surface. The great circle that passes through the sun position and the point connects to another point on the far side of the sphere, 180° from the sun position. Any point on the surface of the sphere will lie on a great circle passing through these two points (see Fig. 2a). On the spherical triangle in Fig. 1, then for a sun location \( s \) and any point \( p \) (Ayres 1954, p.194),

\[
\begin{align*}
a &= 90 - \text{lat}_s \quad b &= 90 - \text{lat}_p, \\
C &= \text{long}_p - \text{long}_s,
\end{align*}
\]

\[
\begin{align*}
B + A &= 2 \tan^{-1}(\cos(0.5(b - a))) \sec(0.5(b + a)) \cot(0.5C), \\
B - A &= 2 \tan^{-1}(\sin(0.5(b - a))) \cosec(0.5(b + a)) \cot(0.5C)),
\end{align*}
\]

and so the sun azimuth (or directional derivative direction) \( \phi \) is given by

\[
\phi = 180 - B.
\]

Fig. 2a shows the azimuth vector \( \phi \) over the surface of the sphere for a given sun location, while Fig. 2b shows vectors oriented at 90° to those of Fig. 2a. The modification of sunshading and directional derivatives
in this manner is an extension of the work of Cooper (2003) from the plane to the sphere.

3. Application to synthetic data

The filter can be used either to enhance or remove both great and small circular features from an image. There are two possible ways to enhance a great circle. Firstly, either of the two poles situated 90° away from the circle can be selected as the filter centre, and radial vectors (as plotted in Fig. 2a) can be used. Secondly, any point on the great circle itself can be chosen as the filter centre, and circular vectors (as plotted in Fig. 2b) can be used. Fig. 3 shows a synthetic dataset consisting of four

---

Fig. 3. Using filter to enhance great circles. (a) Synthetic data consisting of four great circle features with uniformly distributed random noise of amplitude equal to that of circles added. (b) Directional derivative computed using Eq. (1) and azimuths from Eq. (3). Filter centre location is marked as point S₁ in Fig. 3a. (c) Directional derivative computed using Eq. (1) and azimuths rotated 90° from Eq. (3). Filter centre location is marked as point S₂ in Fig. 3a.

Fig. 4. Using filter to attenuate unwanted great circles. (a) Synthetic data consisting of four great circle features with uniformly distributed random noise added. (b) Directional derivative computed using Eq. (1) and azimuths from Eq. (3). Filter centre location is marked as point S₁. (c) Directional derivative computed using Eq. (1) and azimuths rotated 90° from Eq. (3). Filter centre is marked as point S₂.

Fig. 5. Using filter with small circles. (a) Synthetic data consisting of five small circle features with uniformly distributed random noise of amplitude equal to that of circles added. (b) Directional derivative computed using Eq. (1) and azimuths from Eq. (3). Filter centre location is marked as point S. (c) Directional derivative computed using Eq. (1) and azimuths rotated 90° from Eq. (3). Filter centre location is marked as point S.
great circles with random noise added. When the filter centre location is placed at position $S_1$, approximately at the centre of two of the circles, and radial vectors are used, then the result is the enhancement of those circles compared to the other circular features in the image (see Fig. 3b). Alternatively, when the filter centre is placed directly on one of the great circles and circular vectors are used (Fig. 3c), then the great circle is again enhanced. In this case the enhanced great circle alternates in sign between positive and negative (white and black in the figure) as it encounters vectors oriented $180^\circ$ apart.

To attenuate great circles which are interfering with the interpretation of a dataset, the above process is reversed. The filter centre can be placed at either of the two poles situated $90^\circ$ away from the circle and circular vectors can be used, or the filter centre can be placed on the great circle itself and radial vectors used. This process is analogous to the effect of sunshading a normal planar dataset parallel to an unwanted linear feature. In Fig. 4b, the filter centre was placed at the point of intersection of three great circles (marked as $S_1$ in Fig. 4a), and radial vectors were used, attenuating the chosen features effectively. In Fig. 4c, the filter location was placed near the poles of two of the great circles in Fig. 4a (marked as $S_2$ in Fig. 4a). Both of these circles have been diminished in amplitude by using the filter with circular vectors. In this case, however, the great circle that lies close to the equator has been much less attenuated by the filter than it was in Fig. 4b, because the filter’s centre position was much further from its pole than from those of the other two circles.

The filter can be used in a similar manner to enhance or remove small circles of any radii about a chosen centre, as well as great circles. Fig. 5 shows a dataset consisting of three concentric small circles (one on the opposite side of the sphere from the other two) and two additional circles, with uniformly distributed random noise added. When the filter centre is located at the

![Fig. 6. Application to global topographic data. (a) Global topography. Heights are scaled from black (minimum) to white (maximum). (b) Directional derivative computed using Eq. (1) and azimuths from Eq. (3). The filter centre location is marked as point $S_1$ in Fig. 6a. (c) Sun-shaded data computed using Eq. (2) and azimuths rotated $90^\circ$ from Eq. (3). The filter centre location is marked as point $S_2$ in Fig. 6a. The sun elevation was $30^\circ$ from the horizontal.](image-url)
centre of the three concentric circles (marked as S in Fig. 5a) and a filter with radial vectors is used, then these circles are enhanced. Conversely, when a filter with circular vectors is used then these circles are almost entirely removed from the image, leaving only the two additional small circles.

4. Application to global topographic data

Fig. 6a shows an image of global topography at a resolution of one data point per degree. The data are supplied with Matlab, and is available from the National Geophysical Data Center, NOAA US Department of Commerce under data announcement 88-MGG-02. In Fig. 6b, the filter centre was chosen close to the centre of the Pacific ocean (point S1 in Fig. 6a) and radial vectors were used, enhancing the continental edges around the ocean. In Fig. 6c, the filter centre was placed on the mid-Atlantic ridge (point S2 in Fig. 6a), and circular vectors were used with the sunshading algorithm (Eq. (2)) to enhance the ridge itself.

5. Conclusions

Directional derivatives and sunshading are useful algorithms that can be used to enhance or diminish linear features in planar map data. The algorithms have been extended here to allow their use on the surface of the sphere, with both great and small circles. The algorithms were demonstrated on both synthetic data and global topographic data. Matlab source code is available from the IAMG server at www.iamg.org, or from the author on request.

References