DEVELOPMENT AND IMPLEMENTATION OF A DISCRETE GLOBAL GRID SYSTEM FOR SOIL MOISTURE RETRIEVAL USING THE METOP ASCAT SCATTEROMETER

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ABSTRACT/RESUME

Over the last years, the Institute of Photogrammetry and Remote Sensing (I.P.F., Vienna University of Technology) has been putting in practice the retrieval of soil moisture from ERS scatterometer data. Anticipating the operational and partly near-real time creation of soil moisture products based on the existent ERS methods applied to the upcoming ASCAT scatterometer data, we evaluate the appropriateness of four candidate discrete global grids systems (DGG) for processing soil moisture data based on the 25 km ASCAT data. The candidate grids represent the current state of the art both within I.P.F.’s operational processing environments and within the larger scientific community. A simple compliance matrix determines that the grid most suited for our purposes is our own in-house so-called QSCAT grid, a variant of a Sinusoidal Global Grid. Besides the increase of resolution, we implement improvements of the resampling procedures used to transfer scatterometer data from orbit geometry to the global grid.

The present study was funded by the Numerical Weather Prediction Satellite Application Facility (NWP SAF, http://www.metoffice.com/research/interproj/nwpsaf).

1. INTRODUCTION

The Institute of Photogrammetry and Remote Sensing (I.P.F.) of the Vienna University of Technology (TU Wien) has been developing algorithms and software for producing soil moisture data from ERS-1/2 scatterometer data since 1994. The software for processing the scatterometer data is called WARP (soil WAtter Retrieval Package). The most distinct feature of WARP is that all processing is done in the time domain. Since scatterometer data arrive in an image format, with satellite geometry, the data need to be reorganised from an image to a time series format in the first processing step. In order to organise backscatter time series, measurements must be spatially aggregated into sets of regions (so-called grid areas) that partition the surface of the Earth in an approximately regular manner. Such regions form a Discrete Global Grid (DGG) or, if delivered with various resolution steps, a Discrete Global Grid System (DGGS). Each defined grid area is associated with time series of backscatter measurements and holds its own entry in the backscatter metadata database. As part of the continuing development of the WARP package this document focuses upon the assessment and recommendations for the improvement of the currently used DGG in order to accommodate 25 km resolution data from the ASCAT instrument onboard the upcoming MetOp satellite series. For this, four candidate grids obtained by the three main grid generation techniques are compared and evaluated.

2. STATEMENT OF REQUIREMENTS

The design or selection of an appropriate DGG for I.P.F.’s soil moisture product depends on a number of requirements and their specific implications:

Coverage: The grid should be provided by a single solution covering all major land masses of the Earth.

Equal Area: The full information content of the input data should be maintained. This implies uniformly spaced isotropic equal area grid at (at least) twice instrument resolution from which the data is received.

Coordinate system: Coordinate transformation and data location errors should be minimised. The grid should be presented in the same coordinate system as the input satellite data.

Grid Spacing: Interpolation errors due to regridding should be minimised. This requires uniform grid spacing.

Data Access: The requirement for near real time product generation means that the grid design must allow effective handling and gridding of large scatterometer input datasets, with efficient methods for grid indexing and point location in order to effectively transfer data from orbital geometry to the grid system and vice versa.

Resolution: The capability to sufficiently increase or decrease resolution of the grid, to resolve scales of interest should be considered. This raises the question if a congruent grid should be employed.

Resampling: It should be possible to resample the grid in a meaningful manner to any other grid. This will afford maximal possibly for product validation or comparison, either within house, or within the general scientific community.
Knowledge Transfer: Heritage, in terms of knowledge and technology, from I.P.F.’s experience in developing and working with adapted sinusoidal grids should be fully exploited.

3. DISCRETE GLOBAL GRIDS OVERVIEW

There are many different types of discrete global grids each with different properties and therefore different “best” uses, but as discussed in [1], global grids are generally obtained by one of three main techniques:

Partitioning: The most commonly used regular DGGs; the globe is partitioned along the geographic latitude-longitude coordinate system. Its main advantage is that historically the geographic coordinate system is a well known and well used coordinate system and is the basis for a varied number of datasets and processing software. The two dimensional map of the geographic projection is termed the Plate Carrée projection. Grids based on square partitions are familiar and map effectively to common data structures and display devices. Raster data sets are often based upon cell regions with edges defined by arcs of equal angle increments of latitude and longitude (e.g. 0.5°×0.5°, 2.5°×2.5°). Numerous adapted DGGs based upon the geographic latitude-longitude grid have been implemented to address some of the inherent limitations, such as strong distortions at high latitudes. One such adaptation is to decrease the number of cells with increasing latitude to achieve more consistent cell size.

Tiling: With the application of more complex projection systems the partitioning technique evolved into a technique known as tiling. The globe, once in a specified projection, is tiled with a square lattice which forms a DGG. A map projection will either optimise equal area, true shape or true distance or will provide a compromise between them. For global remote sensing applications the most important characteristic of a map projection is that of equal area or equivalence. Therefore area preserving projections such as the cylindrical equal area projection are preferred.

Subdivision: In this case, the globe is inscribed into a platonic solid whose faces are then subdivided into regular shapes, such as triangles, diamonds or hexagons. As noted by e.g. [2], there are only five so-called platonic solids which can be used for this. Although this method generates a DGG with uniform cell dimensions, the cell dimensions cannot be chosen freely but are determined by the particular geometrical division used. The generation of such DGGs is complex, as is the relationship between cell and geographic locations. Whilst tiling or partitioning may be implemented on an ellipsoid definition of the globe, most subdivision techniques limit themselves to the sphere due to increased complexity.

4. CANDIDATE GRIDS

In the following section four candidate DGG’s are presented. The first two are current operational grids used within I.P.F. The other two grids were selected as one represents the most commonly used DGG for handling of earth observation data (the EASE grid), and the final DGG is selected as this is the proposed DGG to be used for the future Soil Moisture and Ocean Salinity (SMOS) mission.

4.1. The WARP4 Grid

The discrete global grid used in WARP version 4.0 for ERS data aggregation is an adapted version of a sinusoidal global grid applied on the sphere [3]. The grid is generated in two steps.

In the first step, a series of latitude small circles are created, equally spaced with a central angle of 0.25° in the south-north direction along any meridian, starting with the south pole (Fig. 1). An Earth radius of 6370 km is assumed, yielding a constant spacing between the latitude circles of

\[ d_\lambda = 6370 \cdot 0.25 \cdot \pi / 180 \approx 27.79 \text{ km}, \] (1)

suitable for the processing of 50 km resolution ERS data [4].

In the second step, the Equator is also divided into 0.25° longitude intervals, giving 4·360=1440 divisions. Each of the latitude circles created above is then subsequently divided into 1440·cos(\lambda) divisions, where \( \lambda \) is the latitude of the circle. This ensures the same 27.8 km spacing in the west-east direction as well, subject to slight variations due to decimal rounding. The number of grid points on each latitude circle decreases thus with increasing latitude and thus addresses high latitude distortion problems noted in [2]. The WARP4 grid covers the land surface of the Earth with more than 180000 single grid areas.

4.2. The QSCAT Grid

The so-called QSCAT grid is very similar to the WARP4 grid described above and was implemented at I.P.F. for storing and processing data from the SeaWinds scatterometer onboard the QuikSCAT platform [5]. Unlike the WARP4 grid, it uses the Geodetic Reference System 1980 (GRS 80) ellipsoid rather than the sphere. Instead of using equal central angles between the latitude circles, it uses an equal arc length of 10 km, calculated as a local spherical (Gaussian) radius [6]. The longitudinal arc distances between grid points on the same latitude circle are also set to 10 km, ensuring consistent arc distances in the west-east direction at the price of a discontinuity at the 180° meridian. Since this region lies mostly in the Pacific Ocean, the discontinu-
ity does not influence retrieval of land parameters, subject to a small area in the Russian far east.

4.3. The EASE Grid

The Equal-Area Scalable Earth Grid (EASE-Grid) was created by the National Snow and Ice Data Center (NSIDC), University of Colorado and the University of Michigan Radiation Laboratory (RADLAB). It was designed to suit the specific needs of SSM/I (Special Sensor Microwave Imager) satellite data, but with a potential for general application to any global scale data set. In the EASE-grid, data can be expressed as digital arrays of varying grid resolutions, defined in relation to one of three possible projections, northern, southern (both in Lambert’s Azimuthal Equal Area projection) and global (in the Cylindrical Equal Area projection). The grid is defined as a rectangular matrix on each of the projections, where each column and row can be easily matched to its latitude-longitude coordinate. Row and column positions are computed differently for each of the possible projections, thus marking EASE as a non-global Earth grid. Another disadvantage is its lack of uniform adjacency (due to the square shape of its cells) and the distortions above mid latitudes in the global projection [7]. Its main advantage is the fact that square cells display very effectively on digital output devices based on square lattices of pixels.

4.4. The SMOS Grid

The proposed grid recommended for implementation for SMOS data was selected to fulfil two main requirements. Firstly, it should maintain full information content of the measured SMOS samples corresponding to a maximum instrument resolution of 30 km. This requirement translated to the necessity to select a uniformly spaced global and isotropic grid at twice the instrument resolution of 15 km. Secondly, interpolation error due to regridding to arbitrary user defined grids should be minimised. This can be achieved by having a uniform intercellular spacing. After a comparison of a number of DGG’s, the Icosahedron Snyder Equal Area (ISEA) Aperture 4 Hexagonal (ISEA4H) DGGS was selected as the prime candidate [1]. The process of creating the grid involves subdividing the 20 equilateral faces of the regular icosahedron into more triangles, yielding 20 hexagons and 12 pentagons on the surface of the sphere (the so-called resolution 1 grid). Higher resolution grids (in discrete steps) are formed by further tessellating the obtained shapes. Constructing the higher-resolution ISEA grids requires usage of complex forward and inverse projection formulas to resolve cartesian to geographic coordinates as well as a relatively advanced indexing system for the created cells.

5. ASSESSMENT OF CANDIDATE GRIDS

As noted in [2], there is no single DGG that can provide an optimum solution for all applications, and so in the DGG assessment, as with any requirement driven solution, the requirement criteria do have an order of importance, and therefore a subjective weighting is applied. In relation to the grid for the ASCAT soil moisture products (hereafter termed the WARP5 grid) it is critical that the requirements concerning efficient data access, geodetic coordinate system, and ease of implementation are fulfilled while keeping an as uniform spacing of the grid cells as possible. The simple compliance matrix in Tab. 1 presents a summary of the assessment of the candidate grids.

6. THE PROPOSED WARP5 GRID

Based on Tab. 1 we conclude that the most suitable candidate grid, with the highest score, is the QSCAT one. We therefore define the WARP5 grid as the QSCAT grid, with the difference of using the GEM6 ellipsoid and a grid spacing arc length of a = 12.5 km. The grid construction procedure described in Section 4.2 applied for WARP5 is illustrated in Fig. 1. The resulting grid configuration for three different areas is shown in detail in Fig. 2, including the discontinuity at the 180° meridian. For more accuracy, the radius of the Earth used for calculating the latitude \( \lambda_j \) of the latitude small circles should be approximated with the radius of curvature of the meridian, given in e.g. [6]. The discrete longitudes along the latitude circles should be calculated using the same Gaussian Earth radius ap-
proximation as for the QSCAT grid [6]. As a measure of the grid spacing (where both the WARP4 and QSCAT grids have been awarded negative marks in Tab. 1), Fig. 3 shows the arc lengths between each grid point and its closest neighbouring grid point (points close to the discontinuity at the 180° meridian excluded). It can be seen that the arc length varies reasonably from 12.455 km at the Equator to the nominal 12.500 km near to the poles. The diagram also shows the increasing interlongitudinal distance between grid points on different latitude circles expressed as the longitudinal angle spanned by two neighbouring points.

Figure 3. Nearest grid point distance and spanned interlongitudinal angle.

7. WARP5 GRID POINT INDEXING

Due to the large number of grid points (3264399 points globally, distributed on 1601 latitude circles), the WARP5 grid configuration would be practically incomplete without fast and effective procedures for grid point indexing and neighbourhood search. In our proposed implementation we allow for regional processing by organising the grid points into 20°×20° cells. We also only consider grid points covering significant land areas, using the land flags included in the scatterometer data or a static external land mask. We save all grid point metadata (latitude, longitude, cell number, etc.) in lookup tables in the form of arrays. Using the array indices for the naming of the files holding the actual backscatter time series for each grid point is an effective way of accessing the data. For the quick resampling of incoming data from orbit to grid geometry we use neighbourhood search routines based on successive geographic coordinate queries. For example, for an incoming data frame of ASCAT measurements one could first find a subset of grid points covering entirely the extent of the data frame, followed by finding the neighbourhoods of the individual frame data nodes within the subset.

8. REFERENCES