A GLOBAL BACKSCATTER MODEL FOR C-BAND SAR

Daniel Sabel[(1)], Marcela Doubková[(1)], Wolfgang Wagner[(1)], Paul Snoeij[(2)], Evert Attema[(2)]

[(1)] Vienna University of Technology, Institute of Photogrammetry and Remote Sensing, Gusshausstrasse 27-29,
1040 Vienna, Austria, Email: ds@ipf.tuwien.ac.at
[(2)] European Space Agency, ESTEC, Keplerlaan 1, P.O. Box 299, 2200 AG Noordwijk, The Netherlands,
Email: paul.snoeij@esa.int

ABSTRACT

The paper presents the first Global Backscatter Model (GBM) for C-band SAR over land, with a resolution of 1 km. The GBM, which has been derived from 55000 ASAR GM datasets, describes the locations specific backscatter characteristics with a linear model. It can be used in support of SAR image interpretation, processing and simulation. The GBM has been used within the Sentinel-1 project for system performance validation.

1. INTRODUCTION

The ENVISAT Advanced Synthetic Aperture Radar (ASAR) offers several different acquisition modes at C-band for continuous Earth observation at global, regional and local scales. As a low-bandwidth background mission, it offers the Global Monitoring (GM) mode with a 1 km resolution. Due to the relatively high temporal sampling of the GM data, it is possible to derive parameters describing the backscattering behaviour of the entire global land surface. Based on time series analysis of more than 55000 GM datasets, the first global backscatter characteristics database at the 1 km scale, called the Global Backscatter Model (GBM), has been derived. The GBM characterises C-band backscatter in HH polarisation for 97% of the global land mass between 60ºS and 70ºN.

It is the intention of the Global Backscatter Model to act as a reference database in support of research as well as SAR image interpretation, processing and simulation.

2. DATASET

The ASAR sensor provides the GM mode as a low-bandwidth background mission with a resolution of 1 km. Due to the low power consumption, the GM mode can be operated potentially continuously. Together with the 405 km wide swath, made possible through electronic beam steering (ScanSAR), revisit times as short as 4 days can be obtained at the equator. Even shorter revisit times can be obtained at higher latitudes, as can be seen in Fig. 1. Due to the relatively short revisit times, when compared to other SAR data, the GM mode is suitable for analysing temporally dynamic phenomena. The temporally dense data also provides an opportunity to characterise general attributes of the land surface, rather than merely its properties at a certain point in time. Furthermore, due to its relatively low spatial resolution, and therefore relatively low storage and processing requirements, it became feasible to carry out a global analysis using high performance off-the-shelf computers.

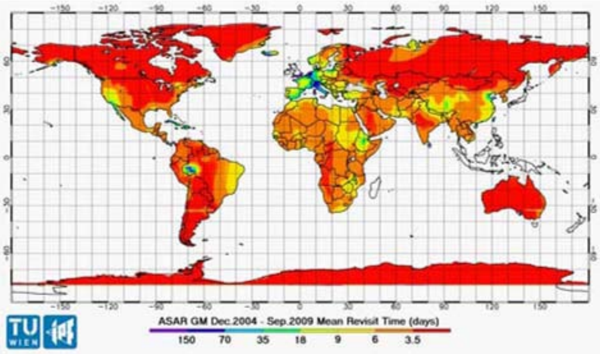

Figure 1. Actual mean revisit times for ASAR GM acquisitions.

Tab. 1 lists technical specifications of the GM data used in the study [1]. The time span of GM data acquisition varied between locations but covers in general the years 2005 to 2008 (4 years).

Table 1. Specifications of ASAR GM data.

Product type	ASA_GM1_1P
Centre frequency	5.331 GHz
Spatial resolution	1000 m
Polarisation	HH
Swath width	405 km
Equivalent no. of looks	7-9
Incidence angle range	17º-42º

Due to the different characteristics of backscatter depending on whether or not the soil is frozen or snow-covered, a meteorological analysis was carried out in the analysis, based on the ERA-Interim dataset, which is produced by the European Centre for Medium Range Weather Forecast (ECMWF) [2]. ERA-Interim data are generated for 91 vertical levels at a spatial resolution of 0.25 degrees and at 00, 06, 12 and 18 UTC time steps [3]. The ERA-Interim parameters used in this study are the snow water equivalent and the 2 metre temperature.

Proc. 'ESA Living Planet Symposium', Bergen, Norway
28 June – 2 July 2010 (ESA SP-686, December 2010)

3. METHOD

Using the SAR Geophysical Retrieval Toolbox (SGRT) developed by TU Wien, the ASAR GM datasets were geocoded, radiometrically calibrated and then resampled to a fixed grid and stored in a database structure suitable for temporal analysis. A surface condition analysis and classification, based on ERA-Interim data was then carry out, followed by a semi-automatic quality control. Finally, the time series of backscatter was for each sample point on the land surface was analysed in order to derive the GBM parameters. The processing is outlined in Fig. 2.

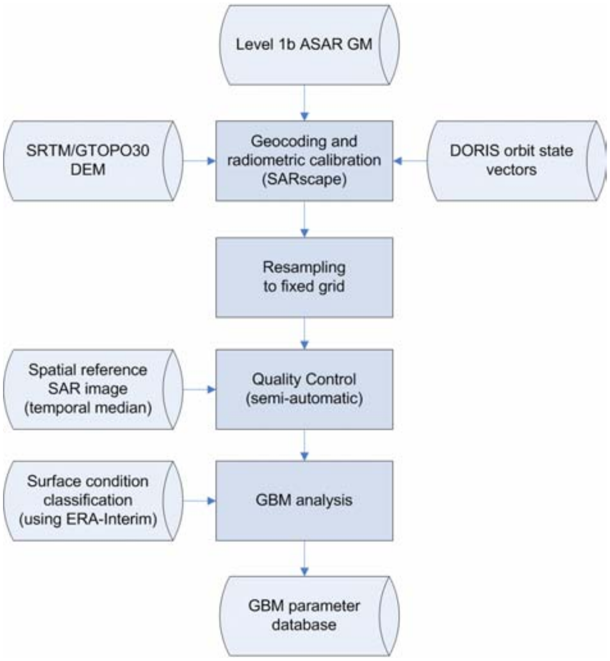

Figure 2. ASAR processing chain for GBM parameter retrieval within the SAR Geophysical Retrieval Toolbox.

3.1. SAR pre-processing

For geocoding and radiometric calibration, SGRT bridges with the SARscape software developed by the company Sarmap. SARscape produces the sigma nought image and, using a model of the satellite orbit and a Digital Elevation Model (DEM), the corresponding local incidence angle estimates. DORIS precise orbit data and a 30 arc-seconds DEM (SRTM) were used. The resampling of these images to a fixed grid in a database was carried out in order to allow efficient time series analysis, which was required for the extraction of the GBM parameters.

3.2. Surface condition classification

As the behaviour of backscatter can vary significantly depending on the presence or absence of snow and frozen soil, meteorological conditions were taken into account in the generation of the GBM parameters. The requirement was that the parameters should be representative of the location specific sampled climatology. It means that if 50% or more of the SAR data for a specific region were acquired over ground conditions unaffected by snow cover and frozen soil, then all measurements used in the generation of the parameters for that region must fulfil similar meteorological conditions. If, however, 50% or more of the SAR data had been acquired over ground conditions without snow cover or frozen soil, then all measurements affected by such conditions were excluded. The analysis was done with a sampling distance of 0.5 degrees. In the first step, the geographically nearest ERA-Interim data was identified. In a second step, each acquisition in the time series was classified into one of two types, based on the snow water equivalent (SWE) and 2 m temperature records from the ERA-Interim data. The Type A condition was defined as surface conditions unaffected by snow cover and frozen soil according to the following criteria:

- Maximum 0.01 mm SWE for 6 hours ahead of and 18 hours prior to GM acquisition.
- Daily minimum temperature above 2°C for 6 hours ahead of and 42 hours prior to GM acquisition.

If either of the two criteria were not met, the corresponding GM data were classified as Type B. Thus, Type B conditions include, but are not limited to, surface conditions affected by snow cover or frozen soil. Fig. 3 shows the dominating surface type.

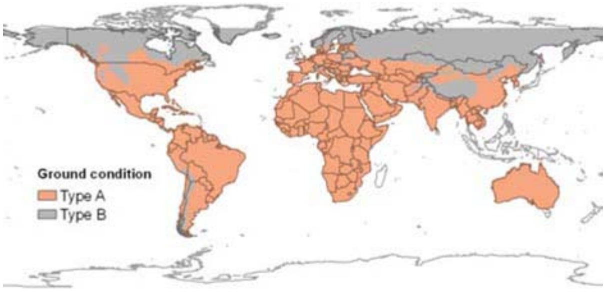

Figure 3. Dominating surface condition (Type A: no snow and non-frozen soil, Type B: other surface conditions).

3.3. Quality control

A semi-automatic quality control and clean-up of the database containing the resampled backscatter was performed in order to minimise the influence of erroneous data (e.g. processing error or corrupt raw data).

3.4. Global Backscatter Model derivation

A linear model was fitted to the time series of sigma nought (σ^0) and local incidence angle (θ) measurements at each grid point, according to Eq. (1), resulting in the GBM parameters slope (k) and intercept (m). Such linear models have been applied in other studies, e.g. in the case of Radarsat data [4] and ERS Scatterometer data [5].

$$\sigma^0(\theta) = m + k\theta \qquad (1)$$

The fitting of the linear model using the least-squares method was carried out for more than 600 million grid points in a 15 arc-seconds grid (~500 m at the equator). Fig. 4 exemplifies, for a single grid point in Arkansas, United States, the relation between sigma nought and the local incidence angle. On average, a time series of about 180 sigma nought and local incidence angle measurements were used for each grid point.

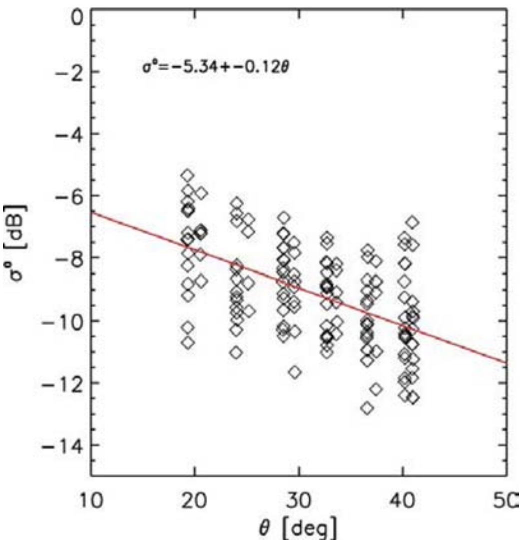

Figure 4. Example of the backscatter dependency on local incidence angle for a location in Arkansas, United States (34.0°N 92.8°W). The equation in the figure shows the intercept and slope parameters of the fitted line (red).

4. RESULTS AND DISCUSSION

Fig. 5 shows a global overview of the slope parameter. Note that for some regions of the world, e.g. United Kingdom, Japan, Madagascar and Oceania, it was not possible to generate GBM parameters due to insufficient ASAR data availability. The slope represents directionality of backscatter, in units of decibel per degree local incidence angle. The slope value depends on the partitioning of backscatter into surface and volume scattering, related to e.g. vegetation density. Dense vegetation, such as rain forests, has slope values close to zero due to the dominating effect of volume scattering, which scatters the radiation in all directions. Open vegetation, such as grasslands or savanna, exhibits more strongly negative slope values due to the higher influence of surface scattering, which allows a greater component of the incoming radiation to scatter away from the sensor. An example of a feature where surface scattering dominates over volume scattering is the Caspian Sea (see Fig. 5), which displays slope values below -0.9 dB/degree. Fig. 6 shows the slope parameter over part of Gabon and Congo in central Africa. In the centre of the image a region heterogeneously covered with savanna can be seen, showing slope values of about -0.4 dB/degree (green). The surrounding rainforest displays values of nearly 0 dB/degree, as the moist and dense crown canopy scatters the radiation in all directions.

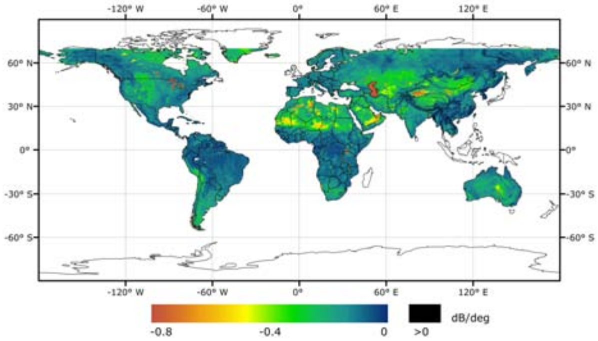

Figure 5. Global overview of the GBM slope parameter.

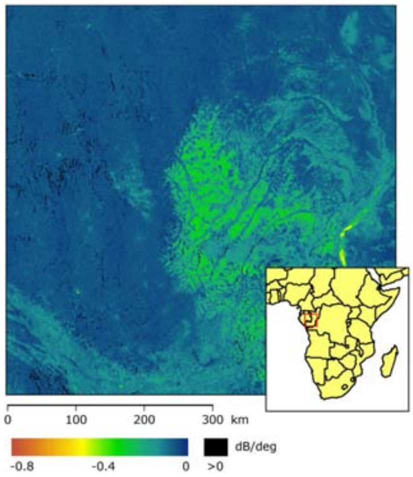

Figure 6. Detail of GBM slope parameter over part Gabon and Congo in central Africa.

The mean sigma nought intensity can be generated with the GBM. For example, settings $\theta=30$ (approximately ASAR mid-swath) in Eq. (1) results in the mean sigma nought intensity at 30 degrees incidence angle ($\sigma^0(30)$). The global image of $\sigma^0(30)$ is shown in Fig. 7.

In general, the GBM parameters are complex functions of land cover, vegetation, soil moisture regime and geomorphologic attributes. A detailed interpretation must also take into account the fact that the ASAR acquisitions used to derive the parameters were acquired over a period of several years. Further research is required for a complete understanding of the GBM parameters.

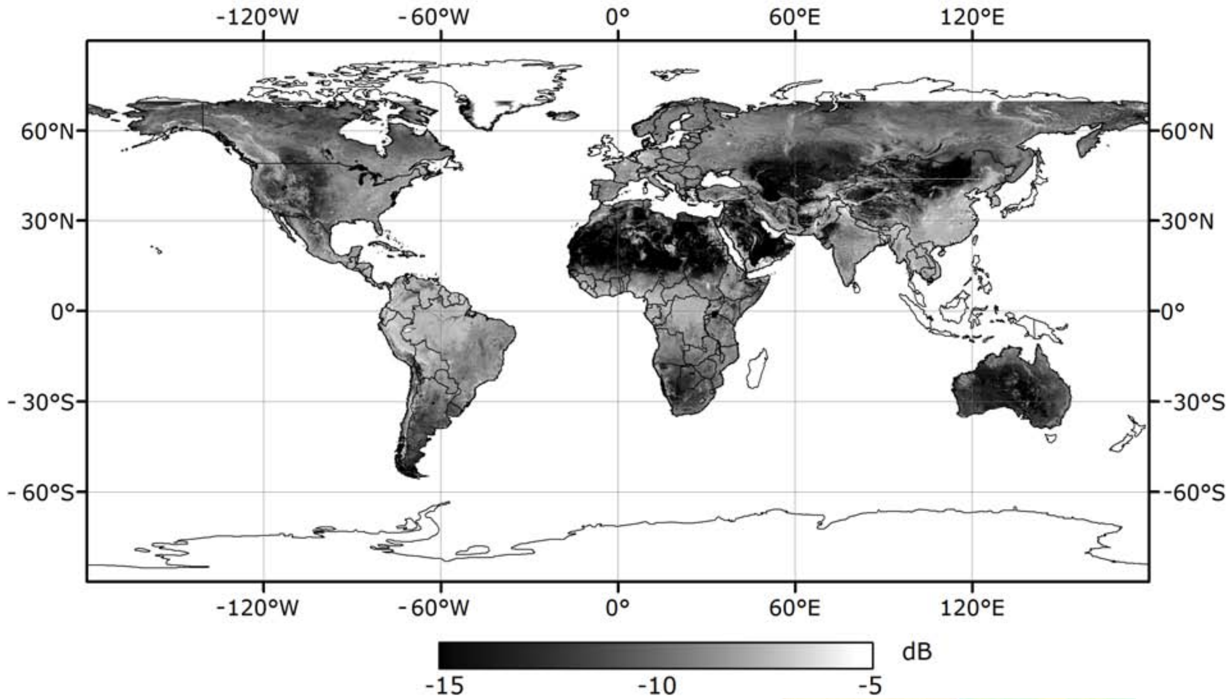

Figure 7. Global image of mean sigma nought intensity at 30 degrees local incidence angle.

The GBM slope parameter has been used to normalise backscatter measurements acquired over the same site, but at different incidence angles, to a single reference incidence angle in order to compare the measurements without the influence of observation geometry. The $\sigma^0(30)$ image (see Fig. 7) provides a spatial reference for C-band backscatter, which can be used as a reference image for georeferencing techniques relying on spatial fitting with a simulated SAR image. This can be especially valuable in areas with limited topographic relief, as such georeferencing techniques often relies on simulated sigma nought images derived from digital elevation models.

The GBM has been used for simulating Sentinel-1 Interferometric Wide Swath (IWS) acquisitions, taking into account local specific backscatter characteristics and the observation geometry. This was done within the project "Sigma Nought Statistics over Land Activity" financed by the European Space Agency in support of system performance validation. The simulation was carried out by coupling the GBM with an orbit simulation and swath determination software. The Sentinel-1 mission will provide continuity of measurement with the ASAR instrument [6].

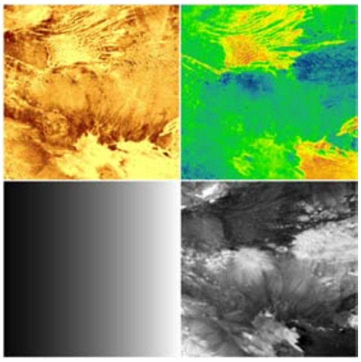

Figure 8. Illustration of sigma nought simulation. Upper row: GBM intercept and slope. Lower row: assumed local incidence angle and resulting simulated sigma nought image. Note that in this illustration, the local incidence angle was estimated without taking the topography into account.

An illustration of the SAR image simulation is given in Fig. 8, which shows the intercept (upper left), slope (upper right), assumed local incidence angle (lower left) and the resulting simulated IWS sigma nought image (lower right). Note that in the illustration in Fig. 8, the local incidence angle was estimated without taking into account the topography.

5. CONCLUSION

The Global Backscatter Model characterises C-band, HH polarisation microwave backscatter for 97% of the global land surface between 60ºS and 70ºN at a resolution of 1 km. The GBM was generated, for more than 600 million locations in a 15 arc-seconds grid, by fitting a time series of backscatter measurements and local incidence angle estimates to a linear model, resulting in a slope and an intercept parameter for each location.

The slope parameter, given in dB/degree, represents the partitioning of backscatter into surface scattering and volume scattering, related to, e.g. vegetation density. The mean sigma nought at any given local incidence angle can be calculated according to Eq. (1). The mean sigma nought intensity, exemplified in Fig. 7, is influenced by e.g. surface roughness, vegetation density and moisture regime.

The GBM can support SAR image interpretation, e.g. for normalisation of backscatter measurements acquired over the same site, but at different incidence angles, to a single reference incidence angle in order to compare the measurements without the influence of observation geometry. The GBM can also be used for SAR image simulation, according to Eq. (1), as has been carried out for simulation of Sentinel-1 IWS acquisitions, taking into account local specific backscatter characteristics and the observation geometry. Furthermore, the GBM SAR simulation capability can also support SAR processing, e.g. as an alternative to simulated SAR images based on DEM relief, as used in e.g. georeferencing techniques relying on spatial regression.

Improvements of the GBM are currently being implemented. The improvements include extending the spatial coverage of the model to cover the entire global land mass, including the Arctic and Antarctic regions.

ACKNOWLEDGEMENTS

The development of the Global Backscatter Model was in part financed by the European Space Agency within the Sigma Nought Statistics over Land Activity (ESA contract No. 22122/08/NL/JA).

The analysis of the ERA-Interim data was carried out within the framework of the Satellite Application Facility on Support to Operational Hydrology and Water Management (HSAF) project of EUMETSAT.

REFERENCES

1. ESA, (2007). ASAR Product Handbook, Issue 2.2.

2. Uppala, S., Kållberg, P. et al. (2004). ERA-40: ECMWF 45-year reanalysis of the global atmosphere and surface conditions 1957–2002. *ECMWF Newsletter 101*.

3. Simmons, A., Uppala, S., et al. (2007). ERA-Interim: New ECMWF reanalysis product from 1989 onwards. *ECMWF Newletter 110*.

4. Mäkynen, M. P., Manninen, T. et al. (2002). Incidence Angle Dependence of the Statistical Properties of C-Band HH-Polarization Backscattering Signatures of the Baltic Sea Ice. *IEEE Transactions on Geoscience and Remote Sensing* **40**(12), 2593-2609.

5. Frison, P.-L. & Mougin, E., (1996). Use of ERS-1 Wind Scatterometer Data over Land Surfaces. *IEEE Transactions on Geoscience and Remote Sensing* **34**(2), 550-560.

6. Attema, E., Snoeij, P. et al. (2008). The European GMES Sentinel-1 Radar Mission. *IEEE International Geoscience & Remote Sensing Symposium 2008*. Boston, MA. 1: I-94 - I-97.