BIOMASS MONITORING WITH SAR

Paul Snoeij(1), Eric Boom(1), Dirk H. Hoekman(2)

(1) Fokker Space B.V.
P.O.Box 32070, 2303 DB Leiden, The Netherlands
Email: P.Snoeij@fokkerspace.nl

(2) Wageningen University
Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands
Email: Dirk.Hoekman@users.whw.wau.nl

ABSTRACT

By mapping the aboveground woody biomass in northern boreal forests and the distribution and accumulation of secondary regenerating forests in the tropics, along with the vegetation in the savannah, biomass measurements will provide insight into the size of the carbon sink. The carbon fluxes however are related to changes in the carbon sink and to green biomass activity and therefore monitoring of vegetation changes and activity are needed. By monitoring the changes in above ground woody biomass and estimation of total biomass and its temporal variability, such a mission will contribute significantly to the understanding of the carbon cycle. Furthermore biomass information is also very important to the economies of various countries both in the tropics and in boreal climates.

Airborne measurements and in-situ ground campaigns cannot provide a homogeneous and frequently updated data set on a global scale, which is collected independent of national interests. Radar backscatter measurements have proven to be positively correlated with aboveground biomass and this correlation increases with the wavelength. Biomass retrieval algorithms have been developed for airborne P-band data collected over both boreal and tropical forests. Radar measurements are insensitive to cloud cover and can be operated during day and night. Hence a spaceborne radar system, operating at low frequency, will permit the measurement, mapping, and understanding of these parameters with a spatial and temporal resolution suitable for modelling ecosystem processes at regional, continental, and global scales. BIOSAR will be a stand-alone mission such that its objective can be met without any additional data, but synergy is expected with using other radar and optical sensors. The main geophysical parameters, which are estimated from the polarimetric radar backscatter measurements performed by this mission, are biomass, flooding condition, and land cover class. Based on experience with airborne campaigns, a polarimetric low frequency SAR has been shown to be the most appropriate instrument to this purpose.

The design philosophy behind a P-band spaceborne SAR is based on small size and low-cost, which should be achieved by using available space qualified hardware components. Also a (relative) small antenna is foreseen, for which an adequate performance will be shown. By merging user and scientific requirements with technical constrains the scenario of a SAR instrument has been investigated. It operates as a normal side-looking synthetic aperture radar and images a 50-km swath positioned such that the incidence angle at mid swath is 23 degrees, which also coincide with the ERS AMI SAR swath and the ASAR IS2 swath.

INTRODUCTION

Data concerning the spatial distribution of vegetation and biomass is becoming an important component of monitoring strategies for the continental carbon balance. A new monitoring capacity for measuring biomass on a global scale in support of the Kyoto Protocol is proposed. The stress on our natural environment is still increasing. The major cause is the rapidly growing global population. Meeting the basic needs for this population places tremendous demands on our natural resources. A few of the most serious environmental problems human society now faces are deforestation, wildlife
and habitat destruction (including loss of biodiversity), air pollution, soil erosion, desertification and loss of wetlands. All of these environmental problems are directly linked to the carbon cycle. Understanding the carbon cycle is therefore crucial to the sustainability of human society. In the context of carbon cycle modelling two aspects of terrestrial biomass need to be clearly separated:

- Carbon sinks represented mainly by the carbon stored in the wood of trees;
- Carbon fluxes caused by carbon sink modification and vegetation activity through respiration.

By mapping the above-ground woody biomass in northern boreal forests and the distribution and accumulation of secondary regenerating forests in the tropics, together with the vegetation in the savannah, biomass measurements will provide insight into the size of the carbon sink. The carbon fluxes however are related to changes in the carbon sink and to green biomass activity and therefore monitoring of vegetation changes and activity are needed. By monitoring the changes in above ground woody biomass and via estimation of total biomass and its temporal variability, such a mission will contribute significantly to the understanding of the carbon cycle. Furthermore biomass information is also very important to the economies of various countries both in the tropics and in boreal climates.

Airborne measurements and in-situ ground campaigns cannot provide a homogeneous and frequently updated data set on a global scale, which is collected independent of national interests. The present suite of spaceborne instruments designed for and/or proposed to the various space agencies around the world does not address the measurement of biomass parameters directly. Most existing optical sensors are not capable of measuring forest biomass or monitoring the dynamics of deforestation and biomass regeneration. There are several reasons for this: 1) insufficient sensitivity to forest structure and above-ground biomass and 2) inadequate temporal frequency as a result of atmospheric conditions (in particular clouds). Radar backscatter measurements have proven to be positively correlated with above-ground biomass and this correlation increases with the wavelength. Biomass retrieval algorithms have been developed for airborne P-band data collected over both boreal and tropical forests. Radar measurements are insensitive to cloud cover and can be obtained during both day and night. Hence a spaceborne radar system, operating at low frequency, will permit the measurement, mapping, and understanding of biomass parameters with a spatial and temporal resolution suitable for modelling ecosystem processes at regional, continental, and global scales [1, 2]. BIOSAR will be a stand-alone mission such that its objective can be met without any additional data, but synergy is expected with other radar and optical sensors. This innovative concept has been presented to ESA which acknowledged in a first evaluation the scientific justifications for the need, usefulness and excellence of the mission. Nevertheless some topics such as frequency allocation, authorisation for experimental use and correction of ionospheric effects require further investigation.

**OBJECTIVES**

The scientific and environmental objective is to improve our understanding of the exchange of carbon between the atmosphere and biosphere by remotely determining the type and the quantity of the above-ground woody biomass and its changes. The motivation for the development of a spaceborne mission is the result of decades of international research and coincident development of more advanced radar imaging systems and their use for mapping various aspects of the Earth’s surface. Scientific field and remote sensing campaigns by ESA and NASA have contributed greatly to the development of algorithms and understanding the sensitivity of polarimetric radar to surface parameters, and in particular showed the unique capability of P-band for measuring forest biomass. Technological advancement has resulted in the development of engineering and calibration techniques that are fine tuned for measuring various Earth surface parameters of interest to the user community (environmentalists, scientific, forest management etc.). Opening a new low frequency spectral window from space will mark a significant and innovative step.

The economical objective is strongly related to the international agreements on carbon exchange and more specifically the Kyoto Protocol along with carbon stock trade principles. Huge investments are needed to reduce the carbon exhaust and the effects of the compliance with the Kyoto Protocol therefore need to be monitored on a national level, a regional level and a global level. The inability to monitor changes related to the carbon cycle, whether positive or negative, will result in inappropriate measures, loss of investments and a reduction in willingness to take further action. The mid and long term the economical consequences (and thus indirectly the effect on the environment) can be huge.

The industrial objective is to strategically position the European industry as a key player in environmental global monitoring missions. The development of advanced technology through science and engineering will provide new capabilities for user oriented spaceborne missions. It is expected that the initial study will lead to an ESA Scientific Opportunity Mission as an intermediate step towards a global monitoring mission. A global monitoring mission might be operated by international agencies and financed by contributions from the future carbon stock trade.

In a long term perspective an operational global monitoring mission shall be planned based on identified user requirements to solve information needs of environmental observation. As a step in between, this feasibility study which is pro-
posed to the European Commission shall lead to a preliminary design of a scientific opportunity mission within the Earth Observation Preparatory Programme of ESA (Fig. 1).

Fig. 1. BIOSAR long term schedule

SAR SYSTEM DESIGN & PERFORMANCE ANALYSIS

By merging user and scientific requirements with technical constrains the scenario of a SAR instrument has been investigated. It operates as a normal side-looking synthetic aperture radar and images a 50 km swath positioned such that the incidence angle at mid swath is 23 degrees which also coincide with the ERS AMI SAR swath and the ASAR IS2 swath. The duration of the scientific mission will be a minimum of two years, with global coverage and a 58 days revisit time. The SAR has been designed to provide a single look spatial resolution of 50 m in ground range and 50 m in azimuth. The major challenge from the perspective of low cost system design is the use of suitable, commercially available antennas [3, 4]. The use of a small existing 4.8 m (or 6.0 m) diameter reflector antenna has various consequences. These two options are considered below however the 4.8 m diameter reflector is presently assumed to be the baseline.

The antenna diameter of 4.8 m results in a broad azimuth antenna beamwidth. This necessitates the use of a higher pulse repetition frequency (PRF) in order to adequately sample the Doppler bandwidth associated with the azimuth beamwidth and thereby achieve acceptable suppression of azimuth ambiguities. The azimuth ambiguities are further suppressed by the choice of processing Doppler bandwidth; a Doppler processing bandwidth of 150 Hz (corresponding to 50 m azimuth resolution) is envisaged which is only a small fraction of the Doppler bandwidth corresponding to the half-power azimuth beam width. The use of higher PRFs results in a reduction in possible swath widths since the echo from the swath must be received in the interval between pulse transmissions. The use of a permissible PRF band at circa 3100 Hz is envisaged for Normal Image Mode.

Preliminary SAR design analysis has been carried out for both antenna options (4.8 m and 6.0 m) using the NEXTPERF software developed by System Engineering & Assessment Limited. This analysis indicates that a reasonable performance can be expected if the system is optimised. The preliminary performance analysis has been conducted assuming a 4.48 m by 4.48 m (5.6 m x 5.6 m) square planar array antenna whose aperture is weighted in elevation and azimuth with a cosine on a pedestal weighting function, \( W(x) = 1 + \gamma \cos(2\pi x/L) \), with \( \gamma \) equal to 0.212 and 0.3 in azimuth and elevation respectively. This antenna has a similar beamwidth to that of a circular reflector with diameter 4.8 m (6.0 m) and has antenna pattern sidelobes of -20 dB in elevation and -17.6 dB in azimuth. The performance analysis has been carried out using the input parameters shown in Table 1.
Table 1. SAR instrument parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft Altitude above Nadir</td>
<td>600 km</td>
</tr>
<tr>
<td>Swath Width</td>
<td>50 km</td>
</tr>
<tr>
<td>Incidence Angle at Mid-Swath</td>
<td>23°</td>
</tr>
<tr>
<td>Spacecraft Speed</td>
<td>7,568 km/s</td>
</tr>
<tr>
<td>Chirp Pulse Bandwidth</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Radar Carrier Frequency</td>
<td>435 MHz</td>
</tr>
<tr>
<td>Range Look Bandwidth</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Range Look Hamming Weighting</td>
<td>0.75</td>
</tr>
<tr>
<td>Number of Range Looks</td>
<td>1</td>
</tr>
<tr>
<td>Azimuth Look Bandwidth</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Azimuth Look Hamming Weighting</td>
<td>0.75</td>
</tr>
<tr>
<td>Number of Azimuth Looks</td>
<td>1</td>
</tr>
<tr>
<td>Average RF power</td>
<td>50 W</td>
</tr>
</tbody>
</table>

The PRFs were chosen to be 5000 Hz and 4500 Hz, respectively, for the 4.8 m and the 6.0 m antennas in the full polarimetric SAR imaging mode. The performance obtained with these input parameters is summarised below in Table 2 for fully polarimetric mode at mid swath. The values for the 6.0 m antenna are in brackets if they differ from those for the 4.8 m antenna.

Table 2. SAR instrument performance parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Range Resolution</td>
<td>47.6 m</td>
</tr>
<tr>
<td>Azimuth Resolution</td>
<td>45.4 m</td>
</tr>
<tr>
<td>IRF Range Peak Sidelobe Ratio</td>
<td>-21 dB</td>
</tr>
<tr>
<td>IRF Azimuth Peak Sidelobe Ratio</td>
<td>-22 dB</td>
</tr>
<tr>
<td>IRF Range Spurious Sidelobe Ratio</td>
<td>-35 dB</td>
</tr>
<tr>
<td>IRF Azimuth Spurious Sidelobe Ratio</td>
<td>-34 dB</td>
</tr>
<tr>
<td>IRF Integrated Sidelobe Ratio</td>
<td>13.6 dB</td>
</tr>
<tr>
<td>Noise Equivalent Sigma Zero</td>
<td>-25 (-29) dB</td>
</tr>
<tr>
<td>Distributed Target Ambiguity Ratio</td>
<td>-13 (-18) dB</td>
</tr>
</tbody>
</table>

This first performance analysis is not sufficient due to the not high enough PRF, which results in an inadequate sampling of the doppler bandwidth. Nevertheless the radar performance will be further optimised, in a fashion which respects the scientific requirements, with regard to: doppler bandwidth sampling, antenna boresight elevation angle, swath position and radar timeline.

If the baseline solution does not perform in a satisfactory fashion, in the fully polarimetric mode, after optimisation, then other possible solutions such as increasing the antenna size, performing ambiguity subtraction or squinting the SAR will be considered. For single polarisation mode the performance figures are basically the same except for the noise equivalent sigma zero performance which is 3 dB better for both antennas, and the distributed target ambiguity ratio at mid swath which is -26 dB for the 4.8 m antenna and -22 dB for the 6.0 m dish.

The 50 m x 50 m single look image data may be smoothed to provide radiometric resolutions of between 5% to 10% (depending on signal-to-noise ratio) at 1000 m by 1000 m spatial resolution which is expected to be sufficient for use in geophysical retrieval algorithms [5]. The radiometric stability of the radar is another source of measurement error in addition to (the ambiguity biases and) the statistical nature of the backscatter measurement. A radiometric stability of between 2.5% and 5% is expected over the lifetime of the instrument given suitable (internal and) external calibration and good platform characteristics. Further examination will be done with respect to instrument subsystem stabilities and spacecraf pointing accuracy and knowledge.

The total payload mass (radar together with data handling, storage and downlink transmission subsystem) is 100 kg, for the smaller antenna design, and 130 kg, for the larger antenna design. The payload peak DC power consumption is 304 W with the radar, the solid state mass memory and the X-band data downlink all running. The radar DC power consumption is 174 W and those of the solid state mass memory subsystem and the X-band downlink subsystem are 80 W and 50 W, respectively. The downlink data rate is 105 Mbits/s. The payload module is partitioned into eight subsystems (Fig.2): 1) The antenna subsystem, 2) The front-end radar equipment subsystem, 3) The high power amplifier subsys-
tem, 4) The power conditioning and distribution subsystem, 5) The radar RF electronics subsystem, 6) The radar digital electronics subsystem, 7) The mass memory subsystem and 8) The downlink subsystem.

The antenna subsystem comprises the reflector antenna, the reflector antenna feed and the coax lines for the V and H signals to and from this feed to the V and H antenna input ports, the mechanical structure required to support the antenna reflector, the antenna feed and coax harness in the correct configuration, the deployment mechanism for the reflector antenna and its associated drive mechanisms and the control for these.

The front-end radar equipment subsystem comprises a switching matrix of coax latching circulators and coax latching isolators, low noise amplifiers and their protection and calibration paths (if required for internal radar calibration). The baseline front-end radar equipment subsystem is depicted in Fig.3. The switching matrix routes signals from the high power amplifier subsystem to either the V or H port of the antenna subsystem and routes V and H signals from both output ports of the antenna subsystem through the low noise amplifiers and then on the two input ports of the Radar RF
Electronics Subsystem. The switching matrix is designed to adequately suppress the transmission of the unwanted polarization during pulse transmission and to protect the LNA from the high powers. The switching matrix is also designed to adequately isolate the two receive channels during echo reception in order to prevent channel mixing within the radar. Each low noise amplifier is proceeded by a limiter to protect it from excessive input powers of sufficient magnitude to damage it. The limiters and low noise amplifiers in each channel are duplicated for reasons of constructive redundancy; both limiters and the low noise amplifiers in each channel are therefore preceded and followed by redundancy switches. The need for internal calibration and the possible need for additional constructive redundancy within the switch matrix will be investigated during Phase A/B. For example signal paths bypassing the LNA may be provided to permit monitoring of the transmitted power.

The high power amplifier subsystem consists of a solid state high power RF amplifier which amplifies the input RF pulse from the radar RF electronics subsystem to a power level suitable for transmission. The output RF signal from this subsystem is input to the front-end radar equipment subsystem for routing to the antenna. A multistage transistor amplifier design is presently foreseen for the SSPA (avoiding the need for multiple parallel channels and power combiners). The solid state high power amplifier will be duplicated for reasons of constructive redundancy. For this reason the two solid state high power RF amplifiers will be preceded and followed by redundancy switches. If required for calibration purposes an additional signal path bypassing the SSPAs will be provided to allow monitoring of the receiver chain.

The Power Conditioning & Distribution Subsystem will supply regulated power to the instrument and the instrument data handling, storage and downlink as required. In particular this subsystem will provide the high current power required by the High Power Amplifier Subsystem during pulse transmission. The subsystem will draw unregulated power from the Nickel-Hydrogen battery in the spacecraft bus.

The radar RF electronics subsystem will perform up and down conversion and all required frequency generation. All frequencies will be derived from an ultra stable local oscillator employing an ovenised quartz crystal oscillator slaved to a rubidium maser (this will not only ensure both good coherence over the flight time of the pulse but also low carrier frequency drift over the instrument lifetime). The subsystem will up convert the coded pulse from the radar digital electronics subsystem from baseband to RF and supply it to the high power amplifier subsystem. The subsystem will down convert the received V and H channel echoes from the front-end radar equipment subsystem from RF to Baseband and supply these signals to receive chain digital electronics in the radar digital electronics subsystem. It is presently envisaged that up and down conversion will be performed by a single stage mixing (without intermediate frequencies) however this will be further investigated during phase A/B.

The Radar Digital Electronics Subsystem provides all timing, sequencing and control signals for the instrument and high level control for the mass memory and downlink equipment. In addition to these functions, the subsystem also generates coded pulses for transmission, samples and quantises the received echoes and performs any required digital filtering and data compression. The main switching signals required by the radar are those needed by the latching circulators and latching isolators in the front end equipment and those required to ensure the transistors in the SSPAs are energised and stable before the RF pulse is triggered. The digital coded pulse generator will employ a single channel memory read-out based system with DAC and high quality low-pass filter; high oversampling and 12-bit wordlength will probably be used to ensure a fully flexible high quality pulse is generated. The receive chain digital electronics unit consists of two identical paths for the V and H channel echoes. Each path contains first a single channel 8-bit ADC (TBC). This may be followed by (bypassable) equipment to perform any required range or azimuth filtering or possibly range compression. This is followed by (bypassable) equipment to perform Block Adaptive Quantisation (BAQ) data compression (or even possibly FFT-BAQ). The architecture of the receive chain digital electronics unit will be reviewed and finalised during Phase A/B. One item which should be considered is the wordlength of the ADC; this could perhaps be chosen to be sufficiently large to avoid the need for any analogue receive chain gain control in the Radar RF Electronics Subsystem. Data output from the Radar Digital Electronics is handled in a format such that the Radar Basic Data Block (RBDB) is the echo data associated with each transmitted pulse; thus a basic data block will contain either one or two lines of echo according to the polarimetric sub-mode in which the radar is operated. Data is transferred from the Radar Digital Electronics Subsystem to the Downlink Subsystem and/or the Mass Memory Subsystem in RBDB format when the radar is operated.

The Mass Memory Subsystem contains a Solid State Mass Memory and a Memory Management Unit. The Solid State Mass Memory has a capacity of 60 Gbits to allow the recording of approximately 10 minutes of data; this corresponds to a swath of length 41.400 km. The Memory Management Unit controls memory address generation and provides the
memory’s interface to the Radar Digital Electronics Subsystem and the Downlink Subsystem. The Mass Memory Subsystem records data from the radar in RBDB format and outputs data in RBDB format on a first-in first-out basis so that data from the Mass Memory Subsystem is identical to data produced directly from the radar for any given single period of radar operation.

The Downlink Subsystem consists of the Coding & Telemetric Frame Generation Unit and the Downlink Unit. The Coding & Telemetric Frame Generation Unit takes each RBDB and codes it for transmission and packs it into a telemetric frame with synchronisation words. The Coding & Telemetric Frame Generation Unit passes digital frames to the Downlink Unit. The Downlink Unit generates and amplifies an X-band carrier to the correct power level and modulates the digital data from the Coding & Telemetric Frame Generation Unit onto it. The X-band carrier is transmitted from a downlink antenna designed to provide a slant range compensating gain over the field of view of the Earth (between the spacecraft nadir and the horizon) and low gain outside of this angular range.

SIMULATION

For the simulation of SAR systems, one has to distinguish between several levels of simulation:

- End-to-end simulation
- Sub-system simulation

An end-to-end system of a SAR system is a extremely complex and difficult task. It comprises the simulation of signal generation and transmission (sensor), target, propagation path, reception and data downlink, SAR processing and thematic processing. Also for huge SAR projects like ERS and Envisat only dedicated parts of the chain were simulated. An end-to-end simulation would be an overkill and is therefore not advised.

In the frame of BIOSAR only parts of this chain should be analyzed by simulation. Links in this chain are:

- The user requirements for primary and secondary applications shall provide the necessary range and the desired accuracy for the biomass to estimate its influence on the carbon cycle.
- The retrieval algorithms for biomass shall be validated against existing data from airborne campaigns.
- A modeling of the target (tropical and boreal forest) shall be provided by the science team based on previous airborne experiments. The different scattering mechanisms (surface, double-bounce and volume scattering) shall be analyzed and understand for several classes of biomass. Emphasis shall be given to the suitable range of incidence angles. The accuracy's of the algorithms and the saturation level for biomass estimation based on low frequency SAR shall be investigated.
- The propagation pass through the ionosphere shall be modeled. The model shall be based on experiments, e.g. done for telecommunication and GPS. The correction algorithms derived from those models have to be tested against measurements (e.g. VHS beacon signal of DORIS at 401.25 MHz or TRANSIT satellites using a 435 MHz downlink with circular polarization). Impacts on the accuracy of the radar data have to be analyzed.
- The performance of the sensor shall be assessed with an ESA approved tool, e.g. IMS of Matra Marconi Research is suitable for this task as it covers also full polarimetric aspects. Some tailoring of the tool with respect to the antenna and a suitable target description for low frequency range shall be done.
- The coverage of the sensor with respect to orbit and repeat cycles shall be assessed by commercial available tools like STK.

IONOSPHERIC EFFECTS

The ionosphere can disturb the measurement made by a P-band radar in a number of ways. Ionospheric effects include dispersion, scintillation and Faraday rotation [6, 7, 8]. Phase dispersion results in corruption of the slant range measurement; this effect is not so significant for BIOSAR in view of the spatial resolutions of smoothed final products. The second effect, scintillation, results in defocussing of the radar impulse response function especially in azimuth. However severe defocusing is only expected to effect BIOSAR very infrequently and mainly in the tropics. The third effect, Faraday rotation, where the plane of polarization is rotated in fashion dependent on the magnetic field the total electron content and the geometry, can be removed provided fully polarimetric measurements are made. For convenience, the ionosphere is divided into four broad regions called D, E, F, and topside. These regions may be further divided into several regularly occurring layers, such as F1 or F2. Fig. 4 shows the regions with the electron concentration profile during daytime.
• **D-Region:** The region between about 50 and 90 km above the Earth in which the (relatively weak) ionization is mainly responsible for absorption of high-frequency radio waves.

• **E-Region:** The region between about 90 and 150 km above the Earth that marks the height of the regular daytime E-layer. Other subdivisions, isolating separate layers of irregular occurrence within this region, are also labeled with an E prefix, such as the thick layer, E2, and a highly variable thin layer, Sporadic E.

• **F-Region:** The region above about 150 km in which the important reflecting layer, F2, is found. Other layers in this region are also described using the prefix F, such as a temperate-latitude regular stratification, F1, and a low-latitude, semi-regular stratification, F1.5. The F-layer is the region of primary interest to radio communications.

• **Topside:** This part of the ionosphere starts at the height of the maximum density of the F2 layer of the ionosphere. The transition height varies but seldom drops below 500 km at night or 800 km in the daytime, although it may lie as high as 1100 km. Above the transition height, the weak ionization has little influence on radio signals.

The ionizing action of the sun's radiation on the Earth's upper atmosphere produces free electrons. Above about 60 km the number of these free electrons is sufficient to affect the propagation of electromagnetic waves. This "ionized" region of the atmosphere is plasma and is referred to as the ionosphere.

Longer wavelength radio signals can be "bounced" off the ionosphere allowing radio communication "over the horizon". This is how the long, medium and short wave radio broadcasts reach receivers over long distances. Because the ionosphere is not a nice smooth "mirror" the signal can be scattered in many directions causing loss of signal strength and interference from other transmitters. The ionosphere is particularly disturbed in the auroral regions, and during magnetic sub-storms.

**Ionospheric Path Delay**

Radio signals are delayed in the ionosphere. This path delay is paired with a phase advance, which means that the signal will be received later compared with a signal travelling in vacuum. Also for all radio signals with a frequency higher than 30 MHz, the ionosphere acts like a disperse medium, i.e., the delay depends on the frequency. The Total Electron Content (TEC) value plays an important role in electromagnetic wave propagation. TEC is defined as the integration of the electron density over the vertical path from the ground to the upper ionosphere. The value of TEC changes with solar activities, and the difference can be a factor of three. There is a close relationship between electron density and solar activities. Units of TEC are $10^{16}$ electrons per square meter.

The effect of the ionosphere on the propagation time $\Delta \tau$ [s] of a radio signal is:

$$\Delta \tau = \frac{40.3}{cf^2} \int N_e ds = \frac{40.3}{cf^2} \cdot TEC \ [s]$$

(1)

$f = \text{the frequency of the radio signal [Hz]}$

$c = \text{velocity of light [m/s]}$

$N_e = \text{the electron density [electrons/m}^3\text{]}$

$TEC = \text{Total Electron Content [TECU]}$

The integral is referred as the total electron content along the transmission path.

Due to the inhomogeneous nature of the ionosphere different path delays will exist over the synthetic aperture, which may lead to distortions in the image. The effects of varying path delay on the image scale in at this moment under investigation.
Spaceborne active sensors are allowed to operate at frequencies allocated to the Earth Exploration Satellite Service (EESS) by the International Telecommunication Union (ITU). These allocations are being made for one or more of the three ITU-regions. An allocation can be made on primary or secondary basis or by footnote (for additional or alternative allocations). At present no primary or secondary allocation for the EESS exists in the table of frequency allocations (part of the ITU Radio Regulations) at frequencies below 1 GHz. Between 1995 and 1997 a number of studies were carried out to assess the potential interference to other services in this band. These studies were presented at ITU-R Study Groups WP7C and JW7-8R. The outcome of these and other similar studies [8] was that a potential of interference to other services in those bands existed, but that the probability of occurrence is low. But more studies are needed to put this issue again on the agenda of WRC which will be able to give further consideration to this matter in 2002/2003 time-frame.

It is expected that the decision on the development of the P-band SAR will be taken in the near future. The only other option presently available to operate a spaceborne SAR in this frequency range is to obtain permission on a national basis. Such a permission would be possible for large countries or a group of adjacent countries for which neighbouring countries would not experience interference from the spaceborne SAR. The countries which have a specific interest in
the data from the spaceborne SAR might consider accepting a limited amount of interference to specific services operating at the same frequencies if knowledge of when and for how long the interference could be experienced.

The 3-dB beamwidth of the 4.8 m antenna is approximately 8.4 degrees. The total beamwidth of the main lobe is 20 degrees (between the first nulls). At an altitude of 600 km this beamwidth corresponds to an illuminated area of about 200 km by 200 km. By reducing the sidelobe level the potential interference to services in neighbouring countries can be minimised. In the band 430 – 440 MHz the amateur (satellite) service and the radiolocation service have primary allocations. In the bands 420 – 430 MHz and 440 – 470 MHz the fixed service (e.g. TV broadcasting) and the mobile service (mobile radio, mobile telephone) have primary allocations [9]. For a global frequency allocation, the potential interference to all of these services has to be considered. However for a 58 day ground track repeat cycle it is clear that it will be infrequent and of short duration.

CONCLUSION

Low frequency SAR has shown to be capable of adequately measuring forest related parameters. The main geophysical parameters that are estimated from the polarimetric radar backscatter measurements performed by the BIOSAR system are biomass, flooding condition, and land cover class. The design philosophy behind the system is based on small size and low-cost, which should be achieved by using already available space qualified hardware components and existing commercially available RF & Microwave components and subsystems. In this frame the performance of a small antenna, with respect to the used wavelength has been shown. Further optimisation will be done to achieve an adequate performance to resolve the needs from the mission’s objectives.

Further BIOSAR related investigations shall be performed in a study proposed to the European Commission. This study will focus in resolving the critical issues in the system design ranging from antenna feasibility up to biomass retrieval algorithms.

ACKNOWLEDGEMENTS

The authors would like to thank F.M. Seifert (formerly Fokker Space, presently ESA/ESRIN), H. de Wolf (Fokker Space), F. Groen (student at the Rijswijk Institute of Technology), N. van de Valk (student at the Delft University of Technology), and P. van Oevelen (Wageningen University) for there valuable contribution to the BIOSAR program and this paper.

REFERENCES


