Effect of the Ionosphere on P-band Spaceborne SAR Images

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Abstract- 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 space-borne radar system, operating at low frequency, will permit the measurement, mapping, and understanding of these parameters with a spatial and temporal resolution suitable for modeling ecosystem processes at regional, continental, and global scales. Based on experience with airborne campaigns, a polarimetric low frequency or P-band SAR has been shown to be the most appropriate instrument to this purpose. One of the disadvantages of the P-band is that in this frequency band ionospheric distortion off the images is expected to be high. A quantitative estimation of the ionospheric influences on P-band imagery needs to be derived, which can lead to orbit parameters, which minimizes the impact of the ionosphere on biomass measurements.

I. INTRODUCTION

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.

II. THE IONOSPHERE

The ionosphere can disturb the measurement made by P-band radar in a number of ways. Ionospheric effects include dispersion, scintillation and Faraday rotation. Phase dispersion results in corruption of the slant range measurement. The second effect, scintillation, results in defocusing of the radar impulse response function especially in azimuth. 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 if fully polarimetric measurements are made.

The ionizing action of the sun's radiation on the Earth's upper atmosphere produces free electrons. Above about 60 km height 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 aurora regions, and during magnetic sub-storms.

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 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 (Fig.1). 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. 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 effect of varying path delay on the image scale is the subject of this paper.
III. VARIATIONS IN THE IONOSPHERE

The electron density shows a lot of periodical variation. Apart from the variation with height, the electron density varies with the activity level of the sun, time of the year, time of the day, and the geographical position. In addition, a number of stochastical effects play a role in the influence of the ionosphere on SAR radar. These stochastical effects cause rapid fluctuation of the electron density and are related to turbulence in the ionosphere. These electron density structures are called scintillation's. Scintillation's can be divided into two groups, one occurring at low latitude and a second one occurring at high latitude.

At high latitude, the aurora can cause severe distortions. This is produced by high-energy electrons from the solar wind, which at the Polar Regions can sometimes break through the barrier of the earth’s magnetic field. These electrons ionize atoms and so cause the electron density to increase. This ionization's also are responsible for the colored spectacles of the northern en southern lights.

Because the aurora effect is caused by solar winds and coupling of the earth’s magnetic field with the magnetic field of the sun, the rate of occurrence and the severity of this effects are dependent on solar activity. At higher solar activity, aurora effects are more likely to occur and will be more severe.

At low latitude the most important scintillation source is F-spread. F-Spread is caused by rod-shaped, magnetic-field-aligned bubbles, which are formed in the F-layer just after sunset and have lifetimes of 2-3 hours. F-Spread is centered around the magnetic equator and has two peaks at plus and minus ten degrees latitude. The edges of the bubbles of F-spread are highly unstable and can be the source of intensity scintillation. F-Spread is more prevalent at equinoxes and summers and occurs preferentially during magnetically quiet periods. F-Spread goes up with increasing sun activity.

IV. THE IMPACT OF THE IONOSPHERE ON SAR IMAGES

WBMOD models scintillation in the ionosphere and returns among other things the percentage of time an user defined level of scintillation is exceeded. WBMOD is a commercial product developed and sold by Northwest Research Assoc., Inc. All data used in WBMOD were taken from satellites at altitudes in excess of 800 km. Because of the height of BioSAR, 600 km, this means that the scintillation level will be overestimated. For more information regarding WBMOD, the reader is referred to [1,2]. The percentage of time the critical state of scintillation is exceeded is obtained using WBMOD.

V. SIMULATION RESULTS

First the values of the limits of the non-scintillation related ionospheric parameters, TEC and its derivatives are determined. The maximum top-value of the phase shift $\phi_{\text{az, top}}$ of the quadratic component is established through simulation of the point spread function. The simulation reveals that limit on the increase of the ISLR of 1 dB is met for $\phi_{\text{az, top}} = 1.65 \pi = 5.17$. The limits on the TEC-value and its derivatives can now be calculated.

Following common practice the reference frequency $f_{\text{ref}}$ is set to 1 Hz. The precise value of the frequency corresponding to the outer scale wavenumber $f_0$ is not important as long as it is much smaller than $1/\tau_{\text{c}}$, where $\tau_{\text{c}}$ is the period of time needed for the satellite to acquire data for one aperture. The value used for $f_0$ is 0.02 Hz. The slope of the phase spectrum $P$ is a quantity that shows little variation. $P$ is set to 2.5 in the equatorial region (between + and – 26 degree latitude and 2.7 outside the equatorial region, following the WBMOD model.
The power density of the phase at 1 Hz (T) is the only parameter left to quantify the level of scintillation. This quantity is limited by means of simulation. In this simulation, the power density spectrum is used to build 250 functions of phase shift as a function of time. For each of these functions the point spread function is evaluated. From these point spread functions, ISLRs and image shifts are determined. The mean ISLR and the mean of the absolute value of the image shift are then calculated.

The result of the simulation of the probability in azimuth image shift for a value of T of 0.32 rad²/Hz and a value of P of 2.7 is presented in fig. 2. The limit for the phase PDS strength parameter, and the limit for the increase of the ISLR of 1 dB, is 0.1 rad²/Hz. For this limit, the boundary set on the ISLR proves to be decisive. The chance of T exceeding 0.1 rad²/Hz was calculated using WBMOD. The results of this calculation for the BioSAR satellite for the previously defined orbit with a local time at descending equatorial crossing of 21:00 on 1 June 2000 was calculated. Information for two different sets of the condition of the earth’s magnetic field (expressed in Kp-index) and the sunspotnumber (SSN) are displayed as two lines in fig. 3. A Kp number from 1 to 3 is considered normal, from 4 to 9 is considered a magnetic storm. A Kp-index of 6 if according to the space weather scale of the National Oceanic & Atmospheric Administration (NOAA) web site a moderate magnetic storm with an occurrence of 50 times per year. A SSN of 150 is a high value for solar minimums and a normal value for solar. A SSN of 250 is even for solar maximums a high value.

VI. CONCLUSIONS

Using appropriate simulation tools the effect of the ionosphere on image quality can be estimated. The ionospheric effects on the images of a P-band SAR satellite can be categorized into three groups: non-scintillation effect, phase scintillation and intensity scintillation. The following conclusions can be drawn for the quantitative estimation of the effect of these groups:

- Non scintillation effects have a negligible impact on the images of a P-band SAR satellite.
- Phase scintillation will sometimes cause the integrated side lobe ratio to increase more than 1 dB in polar regions, which gives an unacceptable image distortion. The chance that this occurs is most of the time smaller than 5% and always smaller than 30% for moderate ionospheric conditions and a dusk-dawn orbit. The effect of phase scintillation in equatorial regions is found negligible, except for local times between 20:00 and 23:00 for the equatorial regions. Image shifts caused by phase scintillation are insignificant in both equatorial and Polar Regions.
- Intensity scintillation will produce intensity fluctuations in excess of 4 dB for Polar Regions with probabilities approaching 100%. Just like phase scintillation, intensity scintillation will only occur between 20:00 and 23:00 for the equatorial regions.

The conclusion regarding the best orbit is, that a dusk-dawn orbit, which does not cross the equator between 20:00 and 23:00 is preferable. This orbit is the least troubled by phase and amplitude scintillation and isn’t will not be affected by F-spread.

REFERENCES