ASSESSMENT OF NEW CORRECTION TECHNIQUES FOR FARADAY ROTATION AND IONOSPHERIC SCINTILLATION: A BIOMASS PERSPECTIVE

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1. BACKGROUND

The European Space Agency BIOMASS mission will use a P-band polarimetric SAR at 435MHz with 6MHz bandwidth to measure above-ground biomass in order to assess the levels of carbon tied up in forests across the globe. It will also be capable of measuring changes in this quantity over its 5-year lifetime. At this wavelength, the ionosphere can strongly affect the signal, the principal effects being Faraday rotation (FR) and ionospheric scintillation.

The physical quantity dictating FR and scintillation effects is the total electron content (TEC), which is the integrated electron concentration along the propagation paths used by the SAR. TEC has large diurnal and seasonal variations, strong dependence on the 11-year solar cycle, and further stochastic time-variation due to magnetic disturbances. It also exhibits marked large-scale spatial structure, with different types of behaviour in the tropics, mid-latitudes, auroral zones and polar caps. Imposed on this overall spatial pattern are small-scale variations (irregularities) whose severity and morphology also varies with region, with particular ‘hotspots’ in the post-sunset equatorial zone, the auroral zones and the polar caps.

This paper addresses the impact of ionospheric scintillation and FR upon SAR performance, within the particular context provided by the proposed BIOMASS mission parameters. It also proposes techniques for the correction - or avoidance - of ionospheric effects, which unchecked could severely impair system performance. Finally, a performance analysis of the new techniques is performed.

2. FARADAY ROTATION

Faraday rotation – the rotation of the polarization vector of a polarized magnetic wave – is caused by interaction between the incoming wave and the free electrons in the ionosphere. Its one-way value may be approximated as [1]

$$\Omega = \frac{K}{f_0^2} \cdot \overline{B \cos\psi \cdot \sec\theta} \cdot \mathrm{TEC}$$

where f_0 is the carrier frequency in Hz, K is a constant of value 2.365×10^4 [A m^2/kg] and B is the magnetic flux density in Wb/m^2; ψ and Θ are the angles the wave-normal makes with the Earth's magnetic field and the downward vertical, respectively. TEC is the total electron content in TEC units (1 TECU = 10^{16} electrons m^{-2}). The "magnetic field factor", $\overline{B\cos\psi \cdot \sec\theta}$, is calculated at a height of 400 km.

Published estimators of FR all suffer from a $\pm k\pi/2$ ambiguity [2-5], which is a particular problem at P-band, where FR can be several radians. Here, a new set of FR estimators [6] is derived from the off-diagonal terms in the measured covariance matrix of a distributed target. These new measures have a $\pm k\pi$ ambiguity, which can be removed by using the global TEC maps provided by the Global Navigation Satellite System (GNSS). This permits unique correction of polarimetric data under arbitrarily large values of FR.

The new estimators have been inter-compared and also compared with the published estimators using simulation. We can identify a preferred estimator that has the lowest sensitivity to both system noise and channel amplitude imbalance amongst all the estimators considered, and has adequate tolerance to channel phase imbalance if calibration can reduce its residual values to around 1^o. However, since no single FR estimator displays optimal resistance to all types of system effect, the choice of estimator will depend upon the likely system error budget.

3. IONOSPHERIC SCINTILLATION

Fluctuations in TEC on short length scales have a profound effect upon the SAR signal through scintillation. Diffraction effects cause small phase perturbations induced at the ionosphere to result in significant phase and amplitude modulation as the signal propagates away from it. The size and nature of these scintillation effects at a given location are dependent upon the ionospheric in situ electron density, the geomagnetic field, the solar conditions and the time of day.

To assess these scintillation effects the ionosphere is modeled as a two-dimensional phase screen at an altitude of 350km. A two dimensional spectral density function for the TEC is assumed, as given by [7], using parameters derived from the Wide-Band Model of the ionosphere [8,9], the International Reference Ionosphere (IRI) and the International Geomagnetic Reference Field (IGRF10). This enables the simulation by spectral methods of phase screens through which a simulated SAR signal is passed.

The level of degradation of system performance due to scintillation as a function of location, local time and solar conditions is derived from these sample phase screens. It is found that for certain locations it is possible to avoid the worst of the scintillations through appropriate choice of satellite orbit parameters. For example, the dawn-dusk orbit proposed for BIOMASS avoids the area of intense scintillation in the post-sunset equatorial sector but will encounter severe effects at high latitudes.

Methods for correcting unacceptable degradation, based on autofocus and on measurements of TEC, are derived and their performance assessed. The correction method employed, and its efficacy, are found to be dependent upon the correlation of the ionospheric phase fluctuations across the synthetic aperture of the radar.

4. REFERENCES

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This abstract is submitted to the session:

"Ionospheric Effects in SAR, PolSAR, and InSAR"

Co-chairs: T.L. Ainsworth & F. Meyer