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Use of IRI to model the effect of ionosphere emission on earth remote sensing at L-band

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Abstract

Microwave remote sensing in the window at 1.413 GHz (L-band) set aside for passive use only is important for monitoring sea surface salinity and soil moisture. These parameters are important for understanding ocean dynamics and energy exchange between the surface and atmosphere, and both NASA and ESA plan to launch satellite sensors to monitor these parameters at L-band (Aquarius, Hydros and SMOS). The ionosphere is an important source of error for passive remote sensing at this frequency. In addition to Faraday rotation, emission from the ionosphere is also a potential source of error at L-band. As an aid for correcting for emission, a regression model is presented that relates ionosphere emission to the total electron density (TEC). The goal is to use TEC from sources such as TOPEX, JASON or GPS to obtain estimates of emission over the oceans where the electron density profiles needed to compute emission are not available. In addition, data will also be presented to evaluate the use of the IRI for computing emission over the ocean.

Keywords: Ionosphere emission; Microwave remote sensing; L-band; IRI; Radiometer

1. Introduction

Microwave remote sensing in the window at 1.413 GHz (L-band), set aside for passive use only, is important for monitoring sea surface salinity and soil moisture (Lagerloef et al., 1995; Le Vine et al., 2001). These parameters are important for understanding ocean dynamics and energy exchange between the surface and atmosphere. In fact, both NASA and ESA plan to launch satellite sensors to monitor these parameters. In particular, a sensor system called, Aquarius, has recently been selected by NASA as an Earth System Science Pathfinder mission to measure salinity globally from space (Koblinsky et al., 2003), and SMOS, a mission to measure soil moisture and salinity, is under development in Europe as one of ESAs Earth Explorer Opportunity missions (Silvestrin et al., 2001).

The ionosphere is an important source of error for passive remote sensing at L-band (Le Vine and Abraham, 2002; Waldteufel et al., 2004). The effect of Faraday rotation is well known. However, emission from the ionosphere is also a potential source of error. This is particularly important in the case of remote sensing of sea surface salinity because of the rather small radiometric sensitivity (0.5 K/psu) and the rather extreme accuracy (0.2 psu) required for applications to the open ocean (Yueh et al., 2001). As a result, emission on the order of 100 mK is important.

The purpose of this manuscript is to present a regression model that relates ionosphere emission to the total electron density (TEC). Since the electron density profiles needed to compute emission are not available over

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ocean, the idea is to possibly use the TEC obtained from sensors on satellites such as TOPEX and JASON or from GPS to estimate the emission with which to correct the radiometric observations at L-band. Another possibility is to use model data entirely, and this paper will also present data to evaluate the use of the IRI for this purpose (computing emission over the ocean).

2. Background

2.1. Faraday rotation

Faraday rotation is a change in polarization that occurs when radiation from the earth surface propagates through the ionosphere to a sensor in space. As a result, horizontally and vertically polarized radiation at the surface becomes mixed when the radiation reaches the receiver in space. Faraday rotation depends on electron density, the geomagnetic field (B) and the angle, Θ_B, between direction of propagation and geomagnetic field (Thompson et al., 1986). At L-band and $\Theta_B \leqslant 89°$, the rotation angle, Ω_F, is approximately (Le Vine and Abraham, 2000; Abraham and Le Vine, 2001):

$$\Omega_F \approx 6950\ B\ \cos(\Theta_B)\ \sec(\theta)\ \mathrm{VTEC}, \tag{1}$$

where θ is the angle between line of sight and nadir and a good approximation for the total rotation angle is obtained using the value of $B\cos(\Theta_B)$ at an altitude of 400 km (Le Vine and Abraham, 2002). This approximation can be used to compute Faraday rotation over the ocean using TEC data (e.g. obtained from TOPEX or GPS) along line of sight together with the approximation, TEC = VTEC sec(θ).

2.2. Ionosphere emission

Because the ionosphere is also lossy (absorbs energy) at L-band, there is both attenuation of signal as it propagates from the surface to a sensor in space and also emission from the ionosphere itself. Attenuation of the signal (e.g. thermal emission from the ocean surface) by the ionosphere is negligible at L-band (Le Vine and Abraham, 2002); however, the thermal emission from the ionosphere can be significant and important in applications such as the remote sensing of sea surface salinity (Yueh et al., 2001). Assuming a stratified ionosphere and using radiative transfer theory, the up-welling radiation $T_\uparrow$ can be written (Blume and Kendall, 1982; Le Vine and Abraham, 2002):

$$T_\uparrow = \sec(\theta)\int_0^h T_{\mathrm{ion}}(z)2\beta(z) \times \exp\left\{-\sec(\theta)\int_z^h 2\beta(x)\mathrm{d}x\right\}\mathrm{d}z, \tag{2}$$

where T_{ion} is the physical temperature of the ionosphere, h is the altitude of the sensor, and $2\beta(z)$ is the attenuation coefficient for power at an altitude z. The attenuation coefficient, β is obtained from the Appelton-Hartree theory and given by

$$\beta = \frac{1}{2c}\frac{\nu_p^2\nu_z}{\nu^2}, \tag{3}$$

where ν_p is the plasma frequency and ν_z is the effective collision frequency (Rishbeth and Garriott, 1969). Computations have been made here using the Mass-Spectrometer-Incoherent-Scatter (MSIS) model (Picone et al., 2002) to generate the profiles of temperature and neutral particle density needed in Eqs. (2) and (3) together with electron density profiles obtained either from measurements (incoherent scatter radar) or from the IRI model (Bilitza, 2001). The calculations were done as a function of altitude in steps of 1 km and then integrated along the ray path to obtain the total $T_\uparrow$ along the line-of-sight between the surface and sensor. The up-welling radiation is due to thermal emission and is the same for both polarizations. Additional details and examples are in Le Vine and Abraham (2002).

A problem that occurs in practice is that the up-welling emission, $T_\uparrow$, is important for remote sensing over the open ocean where real time profiles of the electron density are not available. As a possible solution to this problem we have explored two possibilities: (1) Using model profiles from the IRI; and (2) Using available measured profiles to develop a regression relating $T_\uparrow$ to TEC which is more likely to be available. Data from incoherent scatter sounders (Emery and Barnes, 2003) at three locations, Millstone (42.6N, 71.5W), Arecibo (18.3N, 66.8W) and Jicamarca (11.9S, 76.0W), is used to build the regression and it is found that the regression coefficients do not vary very much over these three different locations. The examples and data to be presented below focus on a local time of 6 a.m. and 6 p.m. because the remote sensing missions proposed for the future will use sun-synchronous orbits with equatorial crossing times close to 6 a.m./p.m.

8. Conclusions

Thermal emission from the ionosphere can be important for future earth remote sensing at L-band (1.4 GHz). This is especially true of measurements such as ocean salinity that require very high accuracy. The problem is also particularly acute for remote sensing over the oceans because over the oceans there is a lack of data such as electron density profiles needed to predict the emission. It was shown in this paper that it might be possible to use TEC as a surrogate for the electron density profiles. Also, it was shown that the IRI gives reasonable prediction at 6 a.m., the local time at which future sensors are expected to operate. The data presented here are limited, but encouraging, and suggest that more work along these lines may be worthwhile.