

Spurious 3rd and 4th Stokes Signals (“Shadowing”) in Polarimetric Microwave Radiometry over Oceans: Origin, Characteristics, and Mitigation

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Passive polarimetric microwave radiometry is a recently developed technique for measuring sea surface wind vectors. Polarimetric radiometers measure the 3rd and/or 4th Stokes parameters (T_U and T_4) in addition to the traditional dual polarized measurements of vertically and horizontally polarized brightness temperatures (T_v and T_h). These four measurements constitute the set of modified Stokes parameters, which completely describes the state of polarization of the earth scene radiation.

WindSat, developed by the Naval Research Laboratory, is the first space-based multi-frequency fully polarimetric microwave radiometer, and has demonstrated the capability of polarimetric microwave wind direction retrieval. WindSat provides risk reduction for the proposed Microwave Imager Sounder (MIS), under procurement for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The WindSat antenna consists of a 1.8 meter aperture offset parabolic reflector with feed horns densely clustered around the focal point of the reflector. T_U and T_4 are derived from the difference of measurements from +/-45 degree linear and left/right circularly polarized channels, respectively.

Sea surface wind direction retrieval depends critically on the accuracy of the T_U and T_4 measurements; a few tenths of a Kelvin accuracy is required to meet the NPOESS wind direction accuracy requirement of 20 degrees at moderate wind speeds. This in turn requires accurate characterization of the cross-coupling of all Stokes parameters into each radiometer channel. Stokes coupling patterns are derived from gain and phase patterns measured or simulated at two orthogonal polarizations prescribed by established antenna pattern measurement procedure¹. The two complex gain patterns for a given channel are transformed to the polarization basis co- and cross-polarized to the earth scene polarization vector corresponding to channel polarization. The squares of the co- and cross-polarized patterns yield the co- and cross-polarized Stokes coupling patterns, while the real and imaginary parts of their product yield the Stokes coupling patterns for the remaining two Stokes parameters into that channel. The Stokes coupling patterns are integrated over the main beam solid angle to yield the Stokes coupling matrix (M-matrix). In ground processing software, the M-matrix is used in the cross-polarization correction to transform the antenna temperature measurements into the earth scene Stokes parameters used for wind direction retrieval.

¹ See for example A.C. Ludwig, “The Definition of Cross Polarization,” IEEE Trans Antennas Propagat., pp. 116-119, Jan. 1973.

Simulations and range measurements for WindSat and other offset parabolic reflectors show that the co-polarized gain patterns for left and right circular polarized channels are offset in the azimuthal antenna coordinate direction; this is the familiar problem of “beam squint.” This offset yields a Stokes coupling pattern of earth scene $T_1 = T_v + T_h$ into the T_4 antenna temperature measurement having two lobes with approximately azimuthally symmetric placement but opposite signs. The opposing signs of the lobes yield low integrated cross-polarization (small M-matrix element) of T_1 into T_4 ; that is, the cross-polarization lobes tend to cancel each other when the antenna views earth scenes with uniform brightness temperatures.

However, these lobes are of significant amplitude, and do not cancel when viewing some types of non-uniform earth scenes. Consider the effect when the radiometer beams scan azimuthally over features with large changes in T_1 occurring over short distances, such as at coastal, cloud, or rain cell boundaries. One lobe views over the boundary before the other, leading to a spurious increase or decrease in the T_4 measurements. The spurious signal disappears as the radiometer continues to scan and both lobes view over the boundary, and reappears with the opposite sign as the radiometer scans off of the feature. The effect, which is maximized for boundaries perpendicular to the scan direction, cannot be removed in the cross-polarization correction, as derivation of the M-matrix requires the assumption of a uniform earth scene. As the coastal, cloud and rain cell boundaries appear to be spuriously highlighted on one side and shadowed on the other in the 4th Stokes measurements, we call this effect “shadowing.” At IGARSS 2006, we derived the nature of the 4th Stokes coupling patterns from simulated antenna patterns, showed how it resulted in the shadowing effect, and presented some significant shadowing signatures in WindSat data, but also showed how the 4th Stokes shadowing effect could be mitigated in instrument design or processing software. At IGARSS 2008, we will briefly review these results.

This year, we analyzed a smaller but more pernicious and complex shadowing effect in 3rd Stokes measurements, which also appears at coastal, cloud, and rain cell boundaries (at nearly any angle relative to the scan), and similarly degrades wind direction retrievals in the vicinity of such features. At IGARSS 2008, we will give a theoretical treatment to show how the phase relationships between co- and cross-polarized antenna gain patterns for offset parabolic reflectors yield a Stokes coupling pattern of earth scene $T_Q = T_v - T_h$ radiation into the T_3 measurements having 4 lobes (“skewed rosette”) with alternating signs. From this and scanning radiometer simulations, we will derive the magnitude of the 3rd Stokes shadowing effect in relation to scan and feature boundary geometry, and compare the results with WindSat images. We will also show that, unlike 4th Stokes shadowing, 3rd Stokes shadowing is an inherent property of polarimetric microwave radiometers utilizing offset parabolic reflectors. But, we will also estimate the sensitivity of the 3rd Stokes shadowing signal to some antenna design parameters to spark discussions of how this effect might be reduced for future on-orbit radiometers, thereby enabling more accurate wind direction retrieval closer to coastlines, cloud systems, and rain cells.