A Polarimetric Survey of Radio Frequency Interference in C- and X-Bands in the Continental United States using WindSat Radiometry

Steven W. Ellingson*

October 24, 2004

Contents

1 Introduction 2
2 WindSat 2
3 Methodology 2
4 Analysis of RFI Source Counts 7

*Bradley Dept. of Electrical & Computer Engineering, 340 Whittemore Hall, Virginia Polytechnic Institute & State University, Blacksburg VA 24061 USA. E-mail: ellingson@vt.edu
1 Introduction

This report presents a preliminary analysis of radio frequency interference (RFI) observed in 6 months of observations in the C- and X-Band channels of WindSat, an Earth-orbiting polarimetric radiometer. In this report, we limit the analysis to observations of the continental United States. This analysis follows the same approach as in previous reports by this author ([1] and [2]). Comparable studies using AMSR-E are reported in [4].

2 WindSat

A detailed description of the WindSat microwave polarimetric radiometer is available in [3]. Here, the details relevant to the analysis in this report are summarized.

WindSat is the primary payload on the U.S. Air Force’s Coriolis satellite, which was launched in January 2003 and is now in an 840 km circular sun-synchronous orbit. The 6.8 GHz radiometer has a bandwidth of 125 MHz and integration time of 5 ms, yielding an absolute accuracy of about 0.75 K. WindSat measures brightness temperature in a footprint approximately 0.5° (in latitude and longitude) in diameter as travels over the Earth. For this reason, the “duty cycle” of observation for any given point on the Earth is very low; on the order of twice per day. After ground-based post-processing, radiometry in fully-calibrated vertical (“V”) and horizontal (“H”) polarizations are provided. (“H” refers to the polarization parallel to the ground, whereas “V” refers to the polarization perpendicular to both “H” and the direction of incidence.) Brightness temperatures observed on the surface of the Earth in both C- and X-Band typically fall in the range 70–330 K. For the purposes of this report, temperatures greater than 330 K are considered RFI, which also corresponds the highest brightness temperature the WindSat radiometer can accurately measure.

The basis of this report was six months of WindSat observations corresponding to the months of September 2003 through February 2004.

3 Methodology

Analysis is most convenient when the observations are spatially requantized to a grid which is rectilinear with respect to latitude and longitude. Each point in the grid defines a pixel for which the brightness temperature statistics are computed. The grid used in this report has spacing equal to four times the mean spacing of the swath data obtained from WindSat. This grid spacing is approximately one-half of a beamwidth, so there is significant spatial overlap in both the WindSat data as well as the observations presented here. This is desirable in that smaller spacings tend to produce results which are somewhat redundant (being finer than the resolution of the instrument) whereas larger spacings tends to lead to large variations in the number of observations per grid point, which could potentially bias the statistics.

Figure 1 shows the actual probability distribution function (PDF) of the number of observations per grid point. An “observation” is defined as follows: For each measurement from WindSat, the grid point nearest the center of the beam is determined, and then this grid point (and no other) is declared to have been observed. Note that each grid point is observed at least 500 times over the six-month period; i.e., ~3 times/day on average. The Gaussian shape of the distribution suggests that the sampling of the Earth’s surface was not significantly biased, and so the results for all grid points observed should have roughly the same statistical significance.

Figure 2 shows the mean and “max hold” C-Band brightness temperatures, displayed as a flat-shaded contour plot. “Max hold” means the maximum brightness temperature ever observed at a certain location. Note that some caution is required in interpreting these results since the graphing routine is essentially interpolating between the grid points to obtain the temperatures at all other points. All plots show clear evidence of non-geophysical brightness temperature distributions in the form of localized “hot spots,” which are not expected to occur naturally. Furthermore, many of these hot spots exhibit unnaturally-bright temperatures (in excess of 330 K) making it almost certain that they are due to man-made RFI. There also seems to be some correlation between hot spots and
population centers, although this association is weak and many large cities show no evidence of a corresponding hot spot.

An odd feature visible in Figure 2 is the bright “plume” along the mid-Atlantic coast in the max hold images. This feature does not appear in the mean data and is therefore most likely associated with some short-term event. Future analyses of the data should attempt to determine resolve the cause.

Figure 3 shows the mean and max hold X-Band brightness temperatures for the vertical and horizontal polarizations. No obvious RFI is visible in these plots; however the bright plume off the mid-Atlantic coast, observed in the C-Band results, is also visible in the max hold results here. This apparent broad bandwidth casts some doubt that the plume is due to man-made RFI, although the possibility exists that the source is a very strong man-made emitter which is capable of simultaneously saturating the C- and X-Band receivers.

Figure 4 shows the mean and max hold X-Band brightness temperatures for the correlation channels “U” and “4”. The values of these correlations due to geophysical mechanisms may be either positive or negative, but in either case is expected to be very small. For this reason, statistics of the magnitudes of these channels were computed, so that RFI could be more easily identified as a large positive value. Unnatural RFI hot spots, similar to those seen in the C-Band results, are clearly apparent. However, the locations do not seem to be well correlated with the C-Band hot spot locations. Furthermore, comparison of the max hold and mean results suggests that these emissions are intermittent; however another possibility is that they are continuous but appear to be scintillating because the emission is directional and so only observed for certain orientations of WindSat with respect to the source.

There are two other notable features in Figure 4. First is the apparent high brightness coincident with coastlines in the [4] results. This is thought to be due to a slight misalignment of the beams leading to imperfect subtraction as the beams pass from water to land or vice-versa. Second is the trail of hot spots running in a North-South line in the Atlantic in the max hold [4] result; this may be associated with the bright plumes observed in the Figures 2 and 3.

Figure 1: Distribution of the number of observations per grid point for the 6 month dataset analyzed in this report.
Figure 2: C-Band Brightness Temperatures, in K.
Figure 3: X-Band Brightness Temperatures (Linear Polarizations), in K.
Figure 4: X-Band Brightness Temperatures (Correlation Channels), in K.
Another way to characterize the brightness temperatures illustrated in Figures 2 through 4 is through PDFs as shown in Figure 5. There is no particular evidence of RFI visible in these plots except for the dramatic spike at the high end of the C-Band max hold PDF.

4 Analysis of RFI Source Counts

In this section we attempt to characterize the temporal behavior of the RFI. Due to the large quantity of data in this 6 month dataset, this is best done in a statistical manner. Furthermore, the only unambiguous criterion for the presence of RFI is brightness temperature in excess of 330 K. We shall refer to a single observation of a brightness temperature in excess of 330 K as an “excess brightness event” (EBE). In this section, we determine the fraction of observations at each grid point which exhibit EBEs, and present the results in terms of a PDF. Since EBEs were observed only in the C-Band data, only the C-Band data is analyzed in this manner. Furthermore, we note that this analysis is sensitive only to the strongest RFI; in truth, there may be plenty of RFI at levels adversely affecting radiometry but which is undetected in this analysis simply because the recorded brightness temperature is less than 330 K. In fact, the prevalence of hot spots below 330 K in the maps presented in the previous section strongly imply that this is the case.

Figure 5: PDF of $T_B$. Blue/Solid: V, Red/Broken: H.
Figure 6: PDF of the fraction of C-Band observations exhibiting EBEs (observations of brightness temperature ≥ 330 K) per grid point. The right plot is the same as the left plot except the horizontal axis is plotted in log scale. “○”: Vertical polarization, “×”: Horizontal polarization.

Figure 6 shows the PDF of C-Band EBEs over the entire 6 month dataset. A few interesting conclusions can be reached from this result. First, we note that only a tiny fraction of the grid points ever exhibit EBEs, and that no grid point shows EBEs on every observation. In fact, the highest rate of occurrence of EBEs was about 70%, which occurred for just one grid point in vertical polarization. Second, we note that the EBE statistics are roughly the same for both linear polarizations. Third, we observe that the PDF seems to be exhibiting a power law relationship $\approx (2 \times 10^{-6})x^{-2}$ for $x > 10^{-2}$ where $x$ is the fraction of EBEs observed per grid point; this is most easily seen when $x$ is plotted in log scale, in which case the PDF plot becomes nearly a straight line. The power law relationship must break down for some value of $x < 10^{-2}$ since the observed result for $x \sim 0$ is nearly 1, which is simply another way of saying that most grid points do not exhibit EBEs. This power law relationship may be a clue that can be used to deduce the source of the EBEs.

Figure 7 shows the rate of C-band EBEs per grid point in map form. We note here that EBE activity seems to be limited to relatively few geographical regions near Los Angeles, CA; Seattle, WA; Tucson, AZ; Washington, PA; Winston-Salem, NC; and Connecticut, to name a few. We further note that areas of EBE activity do not appear as discrete “spikes” with respect to the grid, but rather as a distribution over a relatively large number of adjacent grid points. In fact, the more active EBE regions exhibit a “tail” of diminishing EBE activity with increasing distance from some central point. This tail may be simply the convolution of the beam shape with the actual region of EBE activity, and may be the source of the power law relationship noted above.

We note one more interesting feature of Figure 7, most easily seen in the horizontal polarization results. Note that the region bordering the Mississippi River from the Southern tip of Illinois to the Northern border of Louisiana shows concentrated EBE activity. A somewhat similar feature is seen running North-South through Utah and Idaho, which very closely follows the path of Interstate 15. Other similar linear features can be seen in central Texas and California. Thus, the source of the EBEs may be associated with radio frequency systems in use along these transportation corridors.
Figure 7: Fraction of C-Band observations exhibiting EBEs, per grid point. The color bar is labeled in \(\log_{10}\) scale; i.e., “−1” corresponds to \(10^{-1}\), and so on.
References


