WindSat L2A Product Specification Document

Kyle Hilburn
Remote Sensing Systems
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1. Introduction

Purpose of this document is to describe the data provided in Remote Sensing Systems (RSS) L2A WindSat data files, and the procedure for obtaining brightness temperature T_B from the L2A data. Dataset dimensions are described in Section 2. Dataset variables are described in Section 3. The procedure for obtaining T_B from antenna temperature T_A is given in Section 4. The data files are in a highly compressed binary format. Please use the read code provided by RSS to read the data files.

The WindSat Polarimetric Radiometer was developed by the Naval Research Laboratory Remote Sensing Division and the Naval Center for Space Technology for the U.S. Navy and the National Polar orbiting Operational Environmental Satellite System Integrated Program Office. It was launched January 6, 2003 aboard the Department of Defense Coriolis satellite. Geophysical observations begin February 5, 2003 with RSS orbit number 369. As of May 28, 2014, WindSat is at RSS orbit number 58970. Table 1 gives a list of WindSat data gaps longer than one week.

The antenna temperatures are resampled to the four resolutions given in Table 2 using optimal interpolation [*Poe* 1990]. The resampling is performed for target footprint sizes larger than the source footprint. Thus, the very low resolution has all of frequencies available. The low resolution has all of the fully polarimetric channels. Medium resolution provides the same frequencies as SSM/I, except 85 GHz. High resolution provides only 37 GHz. For WindSat, the resampling is done onto a fixed $1/8^{th}$ x $1/8^{th}$ degree Earth grid.

WindSat is unique in providing both forward-looking Earth observations and backward-looking Earth observations. Figure 1 shows the forward and backward overlap for each frequency. The 6.8 GHz frequency does not have overlap between its forward and backward looks. The 10.7, 18.7, and 37.0 GHz frequencies have substantial overlap on the left side of the swath. The forward/backward overlap for 23.8 GHz is on the right side of the swath. Note that Earth incidence angle is about 0.5° different for forward and backward observations.

Table 1. List of WindSat data gaps longer than one week. Gap length is number of orbits.

Gap Length	Start Orbit	End Orbit	Start Date	End Date
1762	10898	12659	2005-02-12	2005-06-17
856	22880	23735	2007-06-08	2007-08-07
314	28086	28399	2008-06-09	2008-07-01
167	14536	14702	2005-10-27	2005-11-08
133	18584	18716	2006-08-09	2006-08-18
109	14114	14222	2005-09-27	2005-10-05
109	9169	9277	2004-10-14	2004-10-21
103	10648	10750	2005-01-26	2005-02-02

Table 2. WindSat antenna temperature resampling resolutions.

Resolution Name	Nominal Resolution (km)	Available Frequencies (GHz)
Very Low	40 x 60	6.8, 10.7, 18.7, 23.8, 37.0
Low	25 x 38	10.7, 18.7, 23.8, 37.0
Medium	16 x 27	18.7, 23.8, 37.0
High	8 x 13	37.0

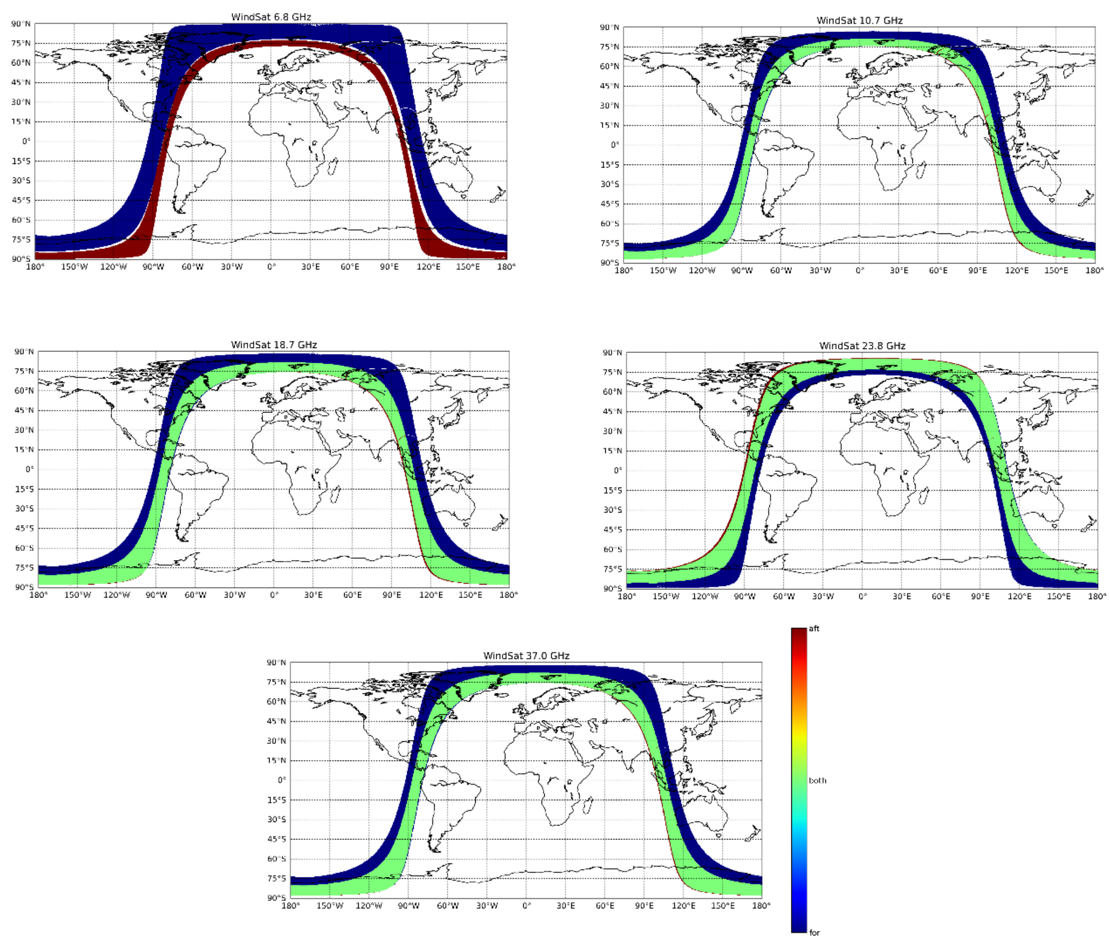

Figure 1. One WindSat orbit showing forward/backward swaths for each frequency. Blue represents forward-look only, red represents backward-look only, and green represents both forward and backward looks in a particular 0.125° x 0.125° cell. From left-to-right, top-to-bottom: 6.8 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, and 37.0 GHz.

2. Dataset Dimensions

This section provides information about the dataset dimensions.

a. Dimension 1

Short name: nfreq

Long name: Number of frequencies

Value: 5

Comments: Frequencies are: 1 = 6.8, 2 = 10.7, 3 = 18.7, 4 = 23.8, and 5 = 37.0 GHz.

b. Dimension 2

Short name: ndir

Long name: Number of look directions

Value: 2

Comments: Look directions are: 1 = forward look, 2 = backward look.

c. Dimension 3

Short name: nlon

Long name: Number of longitude grid cells

Value: 3120

Comments: This is 360° + 30° divided by 0.125°/grid-cell. The longitude index does not represent Earth longitude, but has an offset applied, given by *xlon_node1* variable in the file header. The longitude in degrees East is given by:

$$Longitude = xlon\_node1 - (-0.0625 + 0.125 * ilon)$$

where *ilon* is the longitude index 1 to nlon.

d. Dimension 4

Short name: nlat

Long name: Number of latitude grid cells

Value: 1440

Comments: This is 180° divided by 0.125°/grid-cell. The latitude in degrees North is given by:

$$Latitude = -90.0625 + 0.125 * ilat$$

where *ilat* is the latitude index 1 to nlat.

e. Dimension 5

Short name: maxpol

Long name: Maximum number of polarizations for antenna temperature

Value: 6

Comments: The 10.7, 18.7, and 37.0 GHz channels have all 6 polarizations (vertical, horizontal, +45, -45, Left, Right); while 6.8 and 23.8 GHz have V-pol and H-pol only.

f. Dimension 6

Short name: minfreq_vl

Long name: Minimum frequency index for Very Low resolution

Value: 1

Comments: Very Low resolution has all frequencies.

g. Dimension 7

Short name: minfreq_lo

Long name: Minimum frequency index for Low resolution

Value: 2

Comments: Low resolution has frequencies 10.7 GHz and above.

h. Dimension 8

Short name: minfreq_md

Long name: Minimum frequency index for Medium resolution

Value: 3

Comments: Medium resolution has 18.7 GHz and above.

i. Dimension 9

Short name: minfreq_hi

Long name: Minimum frequency index for High resolution

Value: 5

Comments: High resolution has just 37.0 GHz.

3. Dataset Variables

This section provides information about the dataset variables. The variable dimensions are given in Fortran order (fast-to-slow). For all variables, missing data are given the fill value -1.E30.

a. Variable 1

Short Name: celtim

Long name: Seconds Since 2000-01-01T00:00:00Z

Valid minimum: 97,390,269

Valid maximum: Unlimited

Units: seconds

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: The valid minimum is minimum time from orbit 369.

b. Variable 2

Short Name: celtht

Long name: Earth incidence angle

Valid minimum: 49.0

Valid maximum: 57.0

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: This is the angle between the boresight vector and the local normal where boresight intersects Earth's surface. Minimum and maximum values are calculated from dataset (Fig. 2).

c. Variable 3

Short Name: celphi

Long name: Earth azimuth angle

Valid minimum: -180°

Valid maximum: 180°

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: This is the angle relative to North of the boresight vector at the boresight-Earth intersection. 0° = north, 90° = east, -180° = south, -90° = west.

d. Variable 4

Short Name: celpra

Long name: Polarization rotation angle

Valid minimum: -1

Valid maximum: 1

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: The calculation is documented in *Meissner and Wentz* [2006]. Minimum and maximum values are calculated from dataset (Fig. 2).

e. Variable 5

Short Name: celfrd

Long name: Faraday rotation angle

Valid minimum: -1.5

Valid maximum: 1

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: Calculated using University of Bern total electron content (TEC) maps. Minimum and maximum values are calculated from dataset (Fig. 2), which shows that the Faraday rotation angle generally stays between -1° and +1°. The only time it went out of this range was on October 30, 2003 during a solar flare [*Whitehouse* 2003].

f. Variable 6

Short Name: celsun

Long name: Sun glitter angle

Valid minimum: 0.0

Valid maximum: 180.0

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: Calculated as in *Montenbruck and Gill* [2000].

g. Variable 7

Short Name: celrfi

Long name: Radio frequency interference glitter angle

Valid minimum: 0.0

Valid maximum: 180.0

Units: degrees

Dimensions: (nfreq, ndir, nlon, nlat)

Comments: Calculated based on known geostationary sources of ocean-reflected RFI.

h. Variable 8

Short Name: ta_vl

Long name: Very Low resolution antenna temperature

Valid minimum: 50.0

Valid maximum: 330.0

Units: Kelvin

Dimensions: (nlon, nlat, maxpol, ndir, minfreq_vl : nfreq)

Comments: Methodology for deriving antenna temperature discussed in *Wentz* [2013].

i. Variable 9

Short Name: ta_lo

Long name: Low resolution antenna temperature

Valid minimum: 50.0

Valid maximum: 330.0

Units: Kelvin

Dimensions: (nlon, nlat, maxpol, ndir, minfreq_lo : nfreq)

Comments: Methodology for deriving antenna temperature discussed in *Wentz* [2013].

j. Variable 10

Short Name: ta_md

Long name: Medium resolution antenna temperature

Valid minimum: 50.0

Valid maximum: 330.0

Units: Kelvin

Dimensions: (nlon, nlat, maxpol, ndir, minfreq_md : nfreq)

Comments: Methodology for deriving antenna temperature discussed in *Wentz* [2013].

k. Variable 11

Short Name: ta_hi

Long name: High resolution antenna temperature

Valid minimum: 50.0

Valid maximum: 330.0

Units: Kelvin

Dimensions: (nlon, nlat, maxpol, ndir, minfreq_hi : nfreq)

Comments: Methodology for deriving antenna temperature discussed in *Wentz* [2013].

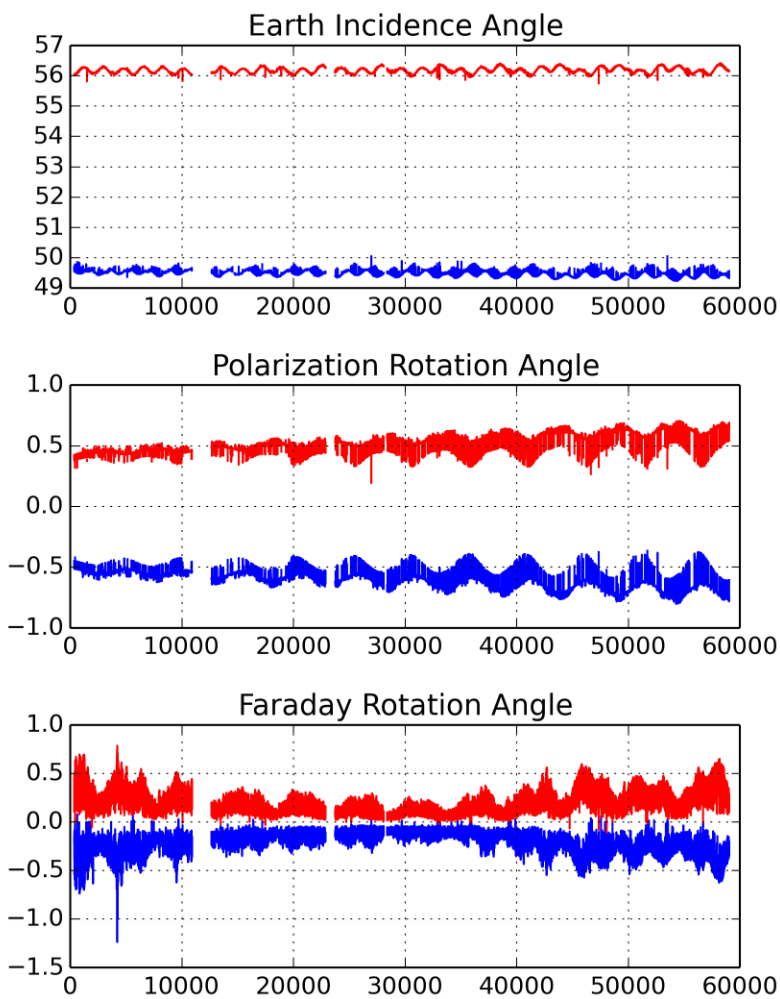

Figure 2. Minimum (blue) and maximum (red) values (in units of degrees) for Earth incidence angle (top), polarization rotation angle (middle), and Faraday rotation angle (bottom) versus orbit number.

4. Calculating Brightness Temperature from Antenna Temperature

First, correct spillover for both polarizations from each horn:

$$T_A' = \frac{T_A - \delta T_{BC}}{1-\delta} \tag{1}$$

where T_A is the antenna temperature, T_{BC} is the cosmic background temperature given in Table 3, and δ is the spillover given in Table 4.

Second, correct cross polarization coupling. To do this, express T_A' in terms of the four-dimensional polarization basis (V,H,3,4):

$$T_A'' = \begin{pmatrix} T_{A1}' \\ T_{A2}' \\ T_{A3}' - T_{A4}' \\ T_{A5}' - T_{A6}' \end{pmatrix} \tag{2}$$

Then take the dot product with the inverse of the cross-polarization matrix C, given in Table 5:

$$T_B' = C \bullet T_A'' \tag{3}$$

Third, correct polarization misalignment. To do this, calculate the total polarization rotation angle, which is a combination of the polarization rotation angle and the Faraday rotation angle

$$\varphi = \varphi_{PR} + \varphi_{FR}\left(\frac{f_2}{f_i}\right)^2 \tag{4}$$

where f_2 = 10.7 GHz and f_i is the i^{th} frequency. Then calculate the polarization rotation

$$\begin{pmatrix} Q' \\ U' \end{pmatrix} = \begin{pmatrix} \cos 2\varphi & -\sin 2\varphi \\ \sin 2\varphi & \cos 2\varphi \end{pmatrix} \begin{pmatrix} T_{B1}' - T_{B2}' \\ T_{B3}' \end{pmatrix} \tag{5}$$

which is used to calculate brightness temperature T_B:

$$T_B = \begin{pmatrix} \frac{1}{2}\left(T_{B1}' + T_{B2}' + Q'\right) \\ \frac{1}{2}\left(T_{B1}' + T_{B2}' - Q'\right) \\ U' \\ T_{B4}' \end{pmatrix} \tag{6}$$

where the primed T_B terms on the right-hand-side are from (3). On the left-hand-side: T_{B1} = vertical polarization, T_{B2} = horizontal polarization, T_{B3} = 3rd Stokes parameter, T_{B4} = 4th Stokes parameter. The methodology used to generate Tables 3, 4, and 5 is described by *Wentz* [2013]. Additional information about the RSS radiative transfer model is given by *Meissner and Wentz* [2012], and additional background information about the calculations in this section are provided by *Meissner and Wentz* [2006]. WindSat geolocation described in *Purdy et al.* [2006].

Table 3. Cosmic background brightness temperatures used in Equation 1.

Frequency (GHz)	T_{BC} (K)
6.8	2.733
10.7	2.738
18.7	2.753
23.8	2.768
37.0	2.821

Table 4. Spillover for each horn used in Equation 1.

Horn	Spillover
6VH	0.02274
10VH	0.01411
10PM	0.01371
10LR	0.01411
18VH	0.01265
18PM	0.01555
18LR	0.01345
23VH	0.01207
37VH	0.01465
37PM	0.01465
37LR	0.01005

Table 5. Inverse of cross-polarization matrix used in Equation 3.

T_B Channel	T_A'' V	T_A'' H	T_A'' T3	T_A'' T4
6 V	1.0065932	-0.0065932	0	0
6 H	-0.0065932	1.0065932	0	0
10 V	1.0022479	-0.0022419	-0.0090164	0.0122545
10 H	-0.0022479	1.0022418	0.0090164	-0.0122545
10 T3	0.0034974	-0.0041597	1.0069391	-0.0028842
10 T4	-0.0020923	0.002094	0.0111096	1.0004864
18 V	1.0093341	-0.009373	-0.0137867	-0.0081204
18 H	-0.0093342	1.0093729	0.0137867	0.0081204
18 T3	0.0048149	-0.0021935	1.0094151	-0.0126359
18 T4	-0.0013228	0.0017951	0.0421254	1.0003127
23 V	1.0145589	-0.0145589	0	0
23 H	-0.0145589	1.0145589	0	0
37 V	1.0035653	-0.003601	-0.0110794	-0.0292365
37 H	-0.0035654	1.003601	0.0110794	0.0292365
37 T3	-0.001739	0.0020863	1.0078826	-0.0350678
37 T4	-0.0063228	0.0074125	0.0283024	1.0037189

5. References

Meissner, T. and F. J. Wentz, 2006: Polarization rotation and the third Stokes parameter: The effects of spacecraft attitude and Faraday rotation, *IEEE Trans. Geosci. Rem. Sensing*, 44, 506-515.

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