AQUARIUS / SAC-D

6th Aquarius/SAC-D Science Meeting

MWR L1 Algorithm & Simulator

Héctor Raimondo & Felipe Madero

19-21 July 2010
Seattle, Washington, USA
MWR Overview & characteristics
Overview & Characteristics

Polarímetro 36.5 Ghz Protoflight

Esquemático Versión 5.0, Actualizado 25/10/2006

Conjunto de llaves de RF

Antenas, OMTs y guias de onda

Canales Analógicos

Subsistema RF

Subsistema de acondicionamiento y adquisición

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Overview & Characteristics

Canal Analógico

Aisladores
EMS
Aisladores
Millitech
Products definitions & Processing levels
Products definitions

- **Basic Products:**
  
  Specification of the Processing Levels:
  
  ✓ Level 0A (raw counts)
  ✓ Level 1A (L0A + earth location)
  ✓ Level 1B1 (L1A + abs. rad. corr.)
  ✓ Level 1B2 (L1B1 + along track resampling)
  ✓ Level 1B3 (L1B2 + map projection)

- **Derived Products:**
  
  ✓ Wind Speed (WS)
  ✓ Wind Direction (WD)
  ✓ Ice Concentration (IC)
  ✓ Columnar Water Vapor (WV)
  ✓ Cloud Liquid Water (CLW)
  ✓ Rain Water (RW)
Basic Products – L0A

- Raw Sample Counts of the instrument
  - Without radiometric/geometric corrections
- Easy to access: The User doesn't need to know the downlink format in order to work with the data
- Includes telemetry from the spacecraft (eph, att) and from the sensor (timestamp, temperatures, etc)
- Includes all auxiliary information needed to make corrections: radiometric coefficients, geometric vectors and matrices, etc.
- Includes information related to the quality of the data (lossed lines, crc problems, etc).
Basic Products – L1A

- Results from applying the following processes to the L0A data:
  - Earth Location parameters calculation (included in the geoloc file)
  - It doesn't contain radiometric corrections (units are digital numbers)
  - It doesn't contain any geometric corrections
  - Contains telemetry information from the spacecraft and sensor
  - Contains information related to the quality of the data
  - Contains all the information needed for the remainder corrections (absolute radiometric correction coefficients, etc)
Each measurement will be associated with the following data:

- Latitude
- Longitude
- Zenith angle to the spacecraft
- Azimuth angle to the spacecraft
- Range to the spacecraft
- Zenith angle to the sun
- Azimuth angle to the sun
- Zenith angle to the moon
- Azimuth angle to the moon
Results from applying the following processes to the L1A data:

- Absolute radiometric correction
- It doesn't contain any geometric corrections
- Contains telemetry information from the spacecraft and sensor
- Contains information related to the quality of the data
- Contains Earth Location Parameters (geoloc)
- Contains all the information needed for the remainder corrections

L1B1 is the main input for the generation of derived products.
Results from applying the following processes to the L1B1 data:

- Along track resampling
- Earth Location parameters calculation (included in the geoloc file)

It doesn't contain any geometric corrections besides along track resampling.

The objective of along track resampling is to reduce superposition among neighbour lines, and probably to improve along track resolution, while maintaining the radiometric performance.

- Contains telemetry information from the spacecraft and sensor
- Contains information related to the quality of the data
- Contains Earth Location Parameters (geoloc)
- Contains all the information needed for the remainder corrections
Basic Products – L1B - L1B3

- Results from applying the following processes to the L1B2 data:
  - Resampling to a Map Projection
  - Earth Location Parameters Calculation
- It is desirable to use L1B2 as input, as the resampling process assume there is no superposition among neighbour measurements at the input.
- Contains information related to the quality of the data
- Contains Earth Location Parameters (geoloc)
- Contains all the information needed for the remainder corrections
Product Performance

- Radiometric Resolution (Noise Equivalent Delta Temperature) is less than 0.5 K rms at all the channels
- Brightness temperature stability is less than 1 K
- Spatial Resolution is less than 54 Km
- Spatial Accuracy is less than 10 Km
Processor: Project, Architecture & Flow Diagram
The MWR processor is being developed as part of the MWP (MicroWave Processors) project at CONAE.

The MWP System is defined as a set of units which shall be part of CUSS (Conae User Segment Service).

The development is guided by a software prototype developed with Python.

The testing will be supported by a MWR simulator which is currently operative, developed also using Python.

The specification of the algorithms to the software provider is based on radiometric and ATBD documents, which were developed hand-in-hand with the software prototype.

The design enables data based parallelization.
Simulation from Windat Data
The first objective of the simulation is to obtain a MWR L1A product using as input a calibrated Windsat Product.

As secondary objectives, it is desirable to obtain L0A products from Windsat Products, and to obtain a tool so as to obtain simulated MWR data from other sources.

The result of this will be used to:

- Develop and test L2 Algorithms and Processors
- Develop and test L1 Prototypes and Processors
• Collaboration with the University of Central Florida in Orlando, Florida.

• Geometrically it is an intelligent resampler of the Windsat product. It doesn't generate an exact MWR Geometry.

• Radiometrically it is based on a conversion from Windsat Bt to MWR Bt, based on a comparison made using a Radiometric Transfer Model.

• It is a matlab based system that is currently being operationally executed at CONAE using a Linux system, with an Octave environment. It generated ENVI products as output.

• Its results has been already submitted to L2 science group.
MWR Geometry and First Version Geometry

Beam 1: Θ = 52° ψ = 24.56°

Beam 8: Θ = 58° ψ = 46.13°

MWR Geometry and First Version Geometry

38.09° EDR Azimuth Range

-27.44°

58° EIA

52° EIA

325.2 Km

46.4 Km

550.6 Km

411.1 Km

Flight Direction
Simulated MWR Orbit with first version

Footprint de MWR simulado a partir de Windsat (código MATLAB, tesis de Salman)
Zoom of products

Windsat Footprint Details.
West Cost of EEUU is resalted in yellow.

First version simulation details.
The different incidence angle of the horns results in the observed stripping.
• CONAE Development. Made using a Python environment.

• Currently its execution is operational. Its results has already been submitted to L2 science group.

• Geometrically, tries to simulate the MWR Geometry as exactly as possible.

• Radiometrically, uses a similar conversion from Winsat Bt to MWR Bt, based on the same Radiation Transfer Model. But also uses the measured antenna pattern as a basis for integration of Windat data.

• It also simulate more exactly the times associated to a MWR acquisition: non null footprint integration time, the 8 measurement cycles, the expected differences between acquisition and time tagging at platform.
Acquisition times

![Diagram showing acquisition times for different beams and cycles, including antenna, S, S+N, and Tc signals.](image-url)
• The second version integrates the Windsat data based on a simulated SAC-D orbit, with simulated yaw steered attitude.

• To get SAC-D state vectors, it is used a SGP4 propagator specifically translated to python for this project. It can also use externally generated state vectors. It remains to add position measurement errors.

• To get attitude, it generates SAC-D yaw steering quaternions. It remains to add attitude measurement errors, and probably, some basic simulator of attitude dynamics.

• A tool has been developed in order to help to obtain the appropriate SAC-D orbit that acquires over a given Windsat Product.
Simulated orbit over a Windsat product
- The radiometric conversion coefficients are configurable in this version.
- The geometric parameters (line of sights, alignment matrices, antenna pattern (typically -3dB) contours, are also configurable.
- We are currently using the best geometric parameters available, which resulted from antenna pattern measurements made at CONAE.
Example measured Line of sight and -3dB contour
• The measured MWR antenna patterns are used to get a weighted mean of the input Windsat footprints over the desired antenna pattern contour.

• It is configurable the contour to use (-3dB, -5dB, -10dB, ...).
Simulated MWR Product

Results from Second Version of simulator
Science and Supplementary Data
The beam number indicates the horn that is being measured for each radiometer. Both radiometers (23.8 GHz and 36.5 GHz) have 8 horns. The 23.8 horns have only V polarization. The 36.5 horns have both V and H polarization.

The 36.5 Ghz radiometer has no receptors for +45 and -45 polarizations. The signals for this polarizations are synthetized from H and V polarizations.

Two horns are measured at the same time, one per each radiometer. The horns of each radiometer are sequentially measured from number 0 to number 7.

Each beam will contain 5 measurements: 23.8_V, 36.5_H, 36.5_V, 36.5_-45 and 36.5_-45.
Microwave Radiometer - Timing Diagram

1.92s

240 ms

30 ms

1 ms (Scatterometer)

10 ms

S Antenna S+N Antenna + Noise Tc Dicke Load

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NASA CONAE SR

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A MWR frame is composed of the following information: science data associated to a beam plus HK data (Id, telemetry data, etc) for the time of acquisition of the beam.

<table>
<thead>
<tr>
<th>Block</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Id</td>
<td>1</td>
</tr>
<tr>
<td>2 - Science Data</td>
<td>15</td>
</tr>
<tr>
<td>3 - Telemetry Data</td>
<td>64</td>
</tr>
<tr>
<td>4 - Thermal Control Parameters</td>
<td>1</td>
</tr>
<tr>
<td>5 - CRC16 - CCITT</td>
<td>1</td>
</tr>
</tbody>
</table>

There are 82 data items each one of 16 bits. (15 science data items (1 beam) = 30 bytes and 67 HK data items & CRC = 134 bytes).
In the telemetry data is contained the temperatures, voltages and currents of the different components of the instrument, plus temperatures of the container of MWR.

The temperatures govern the behaviour of the radiometer. The transfer function of the receptor depends strongly on temperature changes.
### Science Data

<table>
<thead>
<tr>
<th>Science Data</th>
<th>Subsystem</th>
<th>Source</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD-1</td>
<td>MWR – 36.5 GHz</td>
<td>Horizontal Polarization</td>
<td>Signal</td>
</tr>
<tr>
<td>SD-2</td>
<td>MWR – 36.5 GHz</td>
<td>Horizontal Polarization</td>
<td>Signal+Noise</td>
</tr>
<tr>
<td>SD-3</td>
<td>MWR – 36.5 GHz</td>
<td>Horizontal Polarization</td>
<td>Load</td>
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<tr>
<td>SD-4</td>
<td>MWR – 36.5 GHz</td>
<td>+45° Phase</td>
<td>Signal</td>
</tr>
<tr>
<td>SD-5</td>
<td>MWR – 36.5 GHz</td>
<td>+45° Phase</td>
<td>Signal+Noise</td>
</tr>
<tr>
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<td>+45° Phase</td>
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<td>-45° Phase</td>
<td>Signal</td>
</tr>
<tr>
<td>SD-8</td>
<td>MWR – 36.5 GHz</td>
<td>-45° Phase</td>
<td>Signal+Noise</td>
</tr>
<tr>
<td>SD-9</td>
<td>MWR – 36.5 GHz</td>
<td>-45° Phase</td>
<td>Load</td>
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<tr>
<td>SD-10</td>
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<td>Vertical Polarization</td>
<td>Signal</td>
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<tr>
<td>SD-11</td>
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<td>Signal+Noise</td>
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<td>SD-12</td>
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<td>Load</td>
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<td>Horizontal Polarization</td>
<td>Signal</td>
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<td>MWR – 23.8 GHz</td>
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<td>Signal+Noise</td>
</tr>
<tr>
<td>SD-15</td>
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<td>Horizontal Polarization</td>
<td>Load</td>
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<td>--------------</td>
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<td>OP</td>
<td>36.5 H</td>
<td>36.5 +45</td>
<td>36.5 -45</td>
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<td>Ant</td>
<td>S</td>
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<td>Beam7</td>
<td>0x05 0x08</td>
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<table>
<thead>
<tr>
<th>Identificador</th>
<th>Antena 23.8 GHz</th>
<th>Antena 36.5 GHz</th>
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<tbody>
<tr>
<td>0x01</td>
<td>Bocina 2</td>
<td>Bocina 1</td>
</tr>
<tr>
<td>0x02</td>
<td>Bocina 4</td>
<td>Bocina 3</td>
</tr>
<tr>
<td>0x03</td>
<td>Bocina 6</td>
<td>Bocina 5</td>
</tr>
<tr>
<td>0x04</td>
<td>Bocina 8</td>
<td>Bocina 7</td>
</tr>
<tr>
<td>0x05</td>
<td>Bocina 1</td>
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</tr>
<tr>
<td>0x07</td>
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<td>Bocina 6</td>
</tr>
<tr>
<td>0x08</td>
<td>Bocina 7</td>
<td>Bocina 8</td>
</tr>
</tbody>
</table>
Radiometric Corrections
**Antenna Pattern**

- $T_{ML}$: apparent temperature of the scene as observed by the main lobe
- $T_{SL}$: apparent temperature of the scene as observed by the secondary lobe
- $T_{FA}$: physical temperature of the antenna (horn)
- $T_A$: apparent temperature as observed by the antenna
- $T_A'$: temperature transmitted from the antenna to the receptor of the radiometer
- $\eta_L$: radiation efficiency of the antenna
- $\eta_M$: antenna main lobe efficiency ($T_{ML}$)

\[
T_A' = \eta_M \eta_L T_{ML} + \eta_L (1 - \eta_M) T_{SL} + (1 - \eta_L) T_{FA}
\]

\[
T_{ML} = \frac{1}{\eta_M \eta_L} T_A' - \frac{1 - \eta_M}{\eta_M} T_{SL} - \frac{1 - \eta_L}{\eta_M \eta_L} T_{FA}
\]

\[
T_A' = \eta_L T_A + (1 - \eta_L) T_{FA}
\]

If $\eta_L = 1 \Rightarrow T_A' = T_A$

$T_A = \eta_M * T_{ML} + (1 - \eta_M) * T_{SL} \Rightarrow T_{ML} = (1 / \eta_M) * T_A - ((1 - \eta_M)/ \eta_M) * T_{SL}$
Receptor's transfer function:

\[ T_A = \beta_0 + \beta_1 T_0 + \beta_2 T_{FA} + \beta_3 T_{F} + (\beta_4 T_{F} + \beta_5 T_N)D \]

Antenna Pattern:

\[ T_{ML} = \frac{T_A}{\eta_M} + \frac{\eta_M - 1}{\eta_M} T_{SL} \]

where \( T_{SL} \approx 2.7 \text{ K} \)

\( T_{ML} \) : apparent temperature of the scene as observed by the main lobe.

\( T_{SL} \) : apparent temperature of the scene as observed by the secondary lobe.

\( \eta_M \) : efficiency of the main lobe of the antenna.
## Radiometric Calibration

### Datases de Ciencia

<table>
<thead>
<tr>
<th>ID</th>
<th>Antena 23.8 GHz</th>
<th>Antena 36.5 GHz</th>
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</thead>
<tbody>
<tr>
<td>0x01</td>
<td>Bocina 2</td>
<td>Bocina 1</td>
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<tr>
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<tr>
<td>0x08</td>
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<td>Bocina 8</td>
</tr>
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### Función de Transferencia del Receptor + Patrón de Antena

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<thead>
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</table>

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Geometric Corrections
The objectives of the corrections are:

- To be able to obtain the latitude, longitude, and other earth location information, for each pixel in an image, with the best accuracy at hand.
- To be able to interpolate the data along track, so as to reduce overlap and improve geometric resolution, with no reduction on the radiometric quality.
- To resample the bands to a given Map Projection.
Earth Location Parameters

- Plenty earth location parameters are provided: latitude, longitude, range to spacecraft, azimuth and zenith angles to spacecraft, sun, and moon.
- Processor inputs (attitude and ephemeris data) are validated, and when suitable, interpolated.
- Using geometric auxiliar data, such as line of sight vectors derived from antenna pattern measurements made at CONAE, and alignment matrices measured at Brasil.
- The methods used try to obtain the best available accuracy by using systematic methods. So all the needed precession, nutation, polar wander calculations are considered.
- DEM based processing is not needed, as the relevant data is obtained over the oceans.
- As there are few measurements in an scan, there is no need to grid the data. Every measurement will have earth location parameters associated to it.
• Resampling based on a partition of the input space in cells (using the grid of the geoloc), and calculating forward and reverse transformations for each cell, between geodetic coordinates and projected coordinates.

• Transformations calculated using Singular Value Decomposition methods.

• Interpolation currently using NN, Bilinear and CC.

• Currently studying alternatives for doing along track interpolation.
Cross Calibration using Windsat
$T_b$ normalization of WS is needed to adjust differences in frequency and incidence angle with MWR ⇒ RTM used to transform measurements of $T_b$ WS to frequency and incidences angles equivalents to MWR.
Calculate theoretical $T_{b_{\text{MWR}}}$ for geophysical parameters (1° box)

$$T_{b_{\text{MWR}}}^{\text{theoretical}} (f_{\text{MWR}}, \theta_{\text{MWR}}, \text{ws}, \text{SST}, \text{wv}, \text{CLW})$$

Frequency = 23.8 & 36.5 GHz

Incidence Angle = 52° & 58°

Calculate theoretical $T_{b_{\text{WS}}}$ for geophysical parameters (1° box)

$$T_{b_{\text{WS}}}^{\text{theoretical}} (f_{\text{WS}}, \Theta_{\text{WS}}, \text{ws}, \text{SST}, \text{wv}, \text{CLW})$$

Frequency = 23.8 & 37 GHz

Incidence Angle = 53°
\( T_{bMWR}^{\text{measured}} \) and \( T_{bWS}^{\text{measured}} \) (calibrated)

Run RTM in order to:

1. 23.8 GHz:
   - \((v, f_1, \theta_1)\)
   - \((v, f_1, \theta_2)\)

1. 36.5 GHz:
   - \((v, f_2, \theta_1)\)
   - \((h, f_2, \theta_1)\)
   - \((v, f_2, \theta_2)\)
   - \((h, f_2, \theta_2)\)

⇒ We get \( T_{bMWR}^{\text{theoretic}} \) and \( T_{bWS}^{\text{theoretic}} \) (using GDAS data)

\[ \Delta T_b^{\text{theoretic}} = T_{bMWR}^{\text{theoretic}} - T_{bWS}^{\text{theoretic}} \]

⇒ \( T_{bMWR}^{\text{predicted}} = T_{bWS}^{\text{measured}} + \Delta T_b^{\text{theoretic}} \)
Then:
\[ \Delta = \text{Bias}_{\text{MWR}} = T_{\text{bMWR}}^{\text{measured}} - T_{\text{bMWR}}^{\text{predicted}} \]

So, \( \Delta \) vs time:

Variations with time implies corrections, if is constant or varies a little implies no corrections.
Product Format
Product formats

- Processor output: XML files.

- CUSS will have libraries and tools to automatically generate (from XML files) products in HDF5, and other, formats.

- CUSS will pack the products using any packing format (rar, zip, gz, tar, etc). The content of the packet file will be:
  - A folder with the product (XML, HDF5, GeoTiff),
  - The associated metadata in XML format
  - Any other needed data such as calibration files, and auxiliary data files.