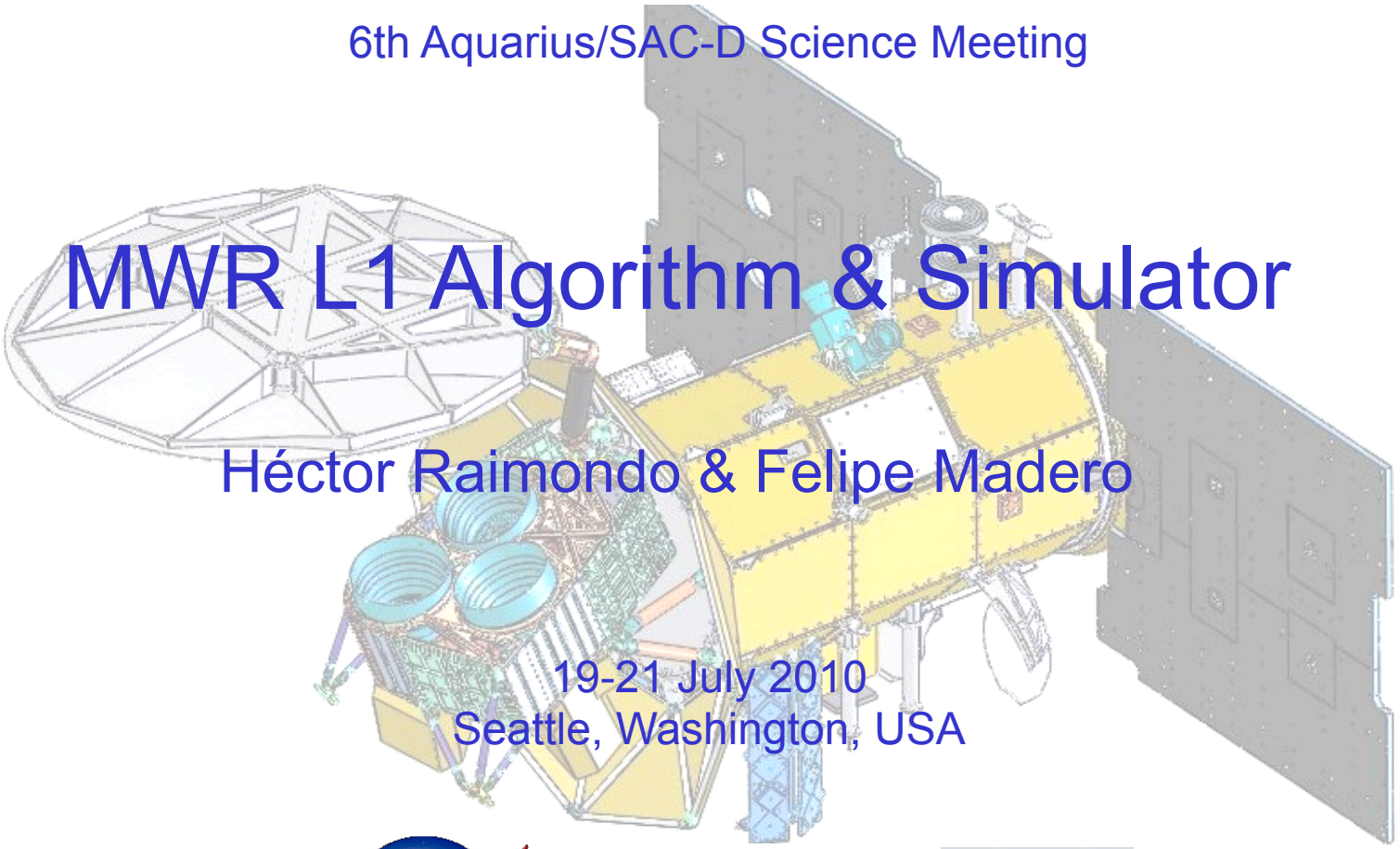
AQUARIUS/SAC-D

6th Aquarius/SAC-D Science Meeting

MWR L1 Algorithm & Simulator

Héctor Raimondo & Felipe Madero

19-21 July 2010
Seattle, Washington, USA



NASA

CONAE
COMISION NACIONAL DE ACTIVIDADES ESPACIALES

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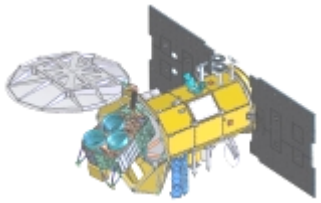
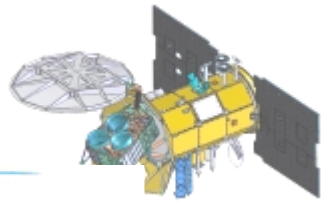
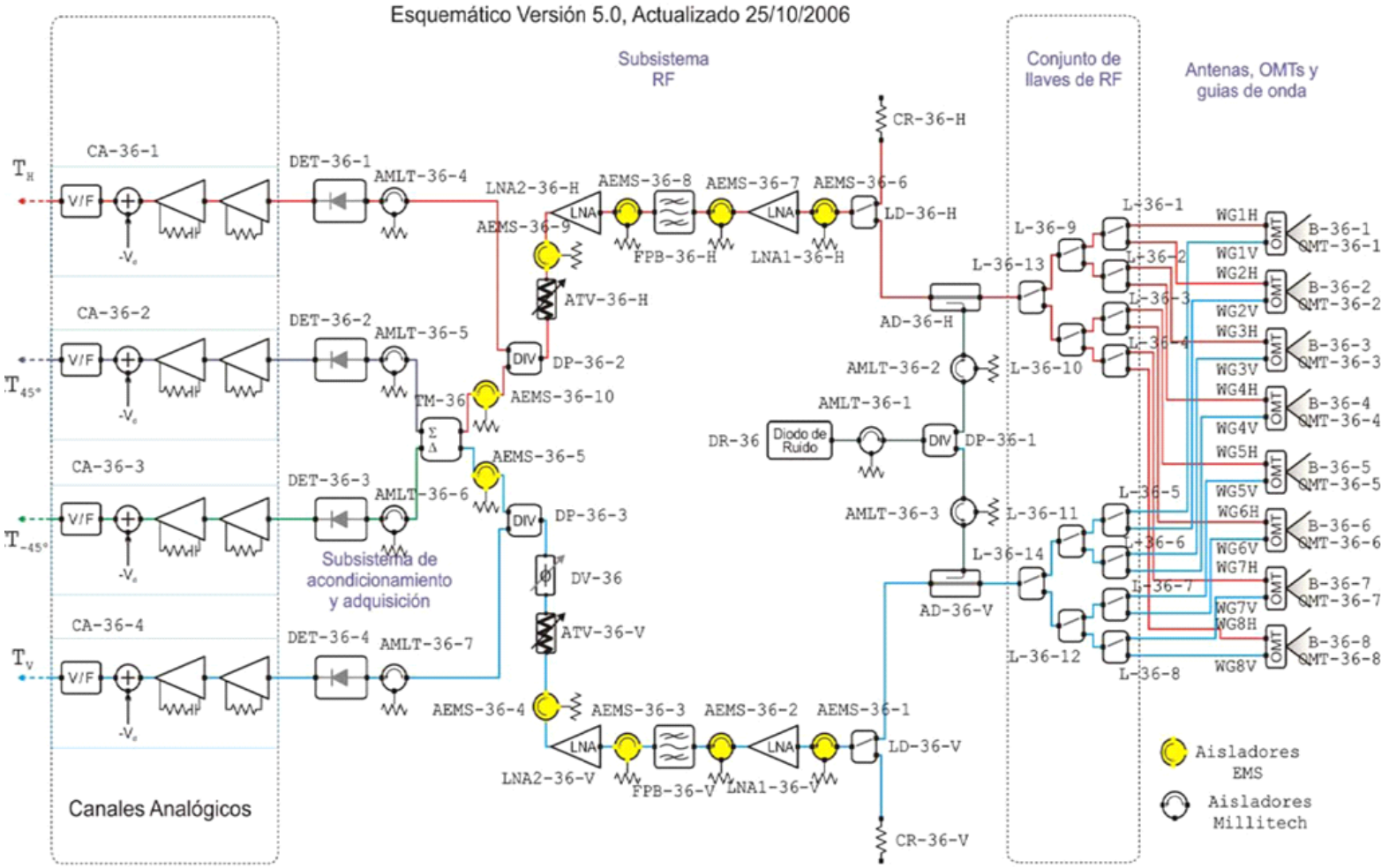


MWR Overview & characteristics

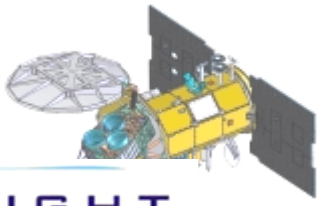
Overview & Characteristics



POLARÍMETRO 36.5 GHZ PROTOFLIGHT

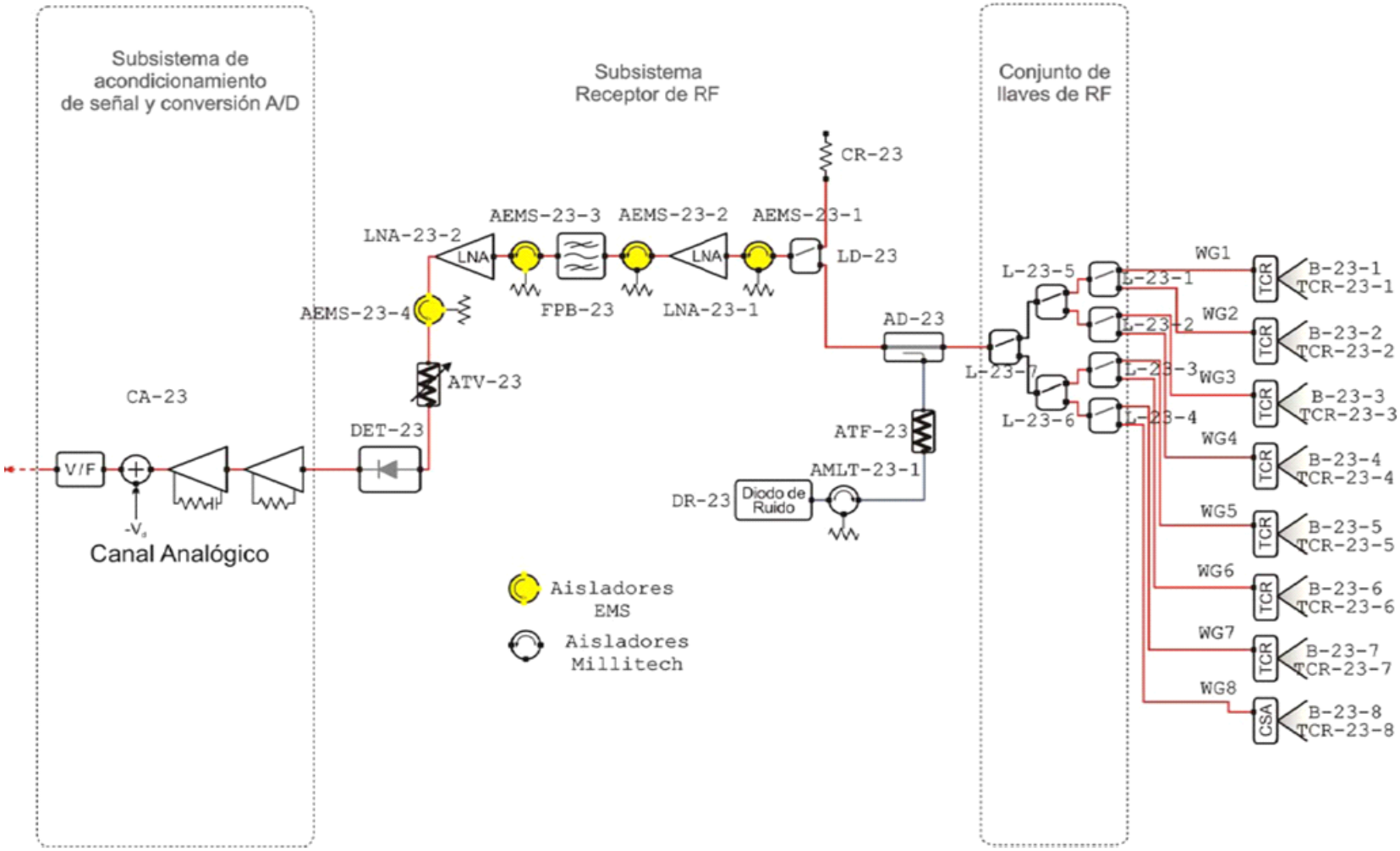


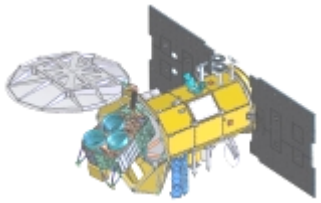
Overview & Characteristics



RADIÓMETRO 23.8 GHZ PROTOFLIGHT

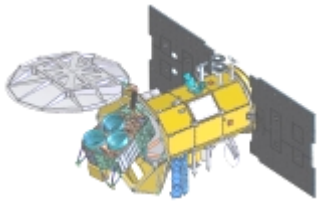
Versión 5.0, Actualizado 25/10/2006





Products definitions
&
Processing levels

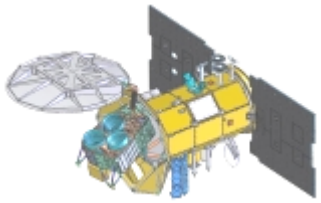
Products definitions



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

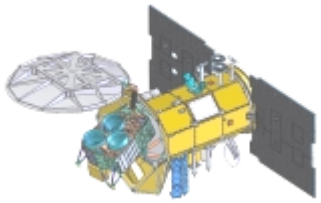
- Derived Products:
  - ✓Wind Speed (WS)
  - ✓Wind Direction (WD)
  - ✓Ice Concentration (IC)
  - ✓Columnar Water Vapor (WV)
  - ✓Cloud Liquid Water (CLW)
  - ✓Rain Water (RW)

Basic Products – L0A



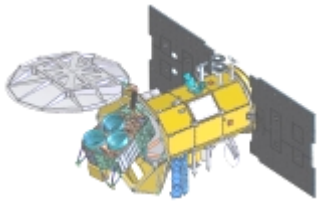
- Raw Sample Counts of the instrument
  - Without radiometric/geometric corrections
- Easy to access: The User doesn't need to know the downlink format in order to work with the data
- Includes telemetry from the spacecraft (eph, att) and from the sensor (timestamp, temperatures, etc)
- Includes all 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)

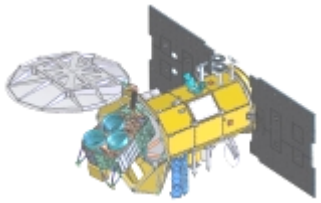
Geoloc File Contents



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

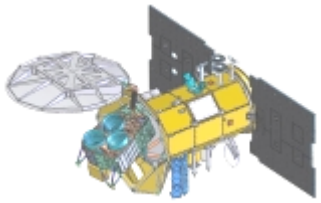
Basic Products – L1B - L1B1



- 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

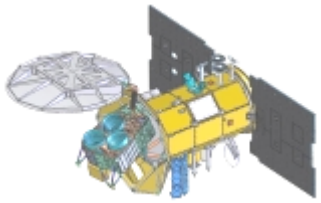
L1B1 is the main input for the generation of derived products.

Basic Products – L1B - L1B2



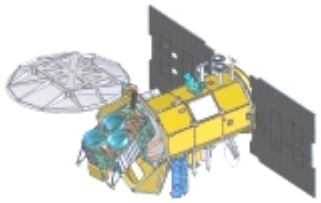
- Results from applying the following processes to the L1B1 data:
  - Along track resampling
  - Earth Location parameters calculation (included in the geoloc file)
- It doesn't contain any geometric corrections besides along track resampling
- The objetive of along track resampling is to reduce superposition 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

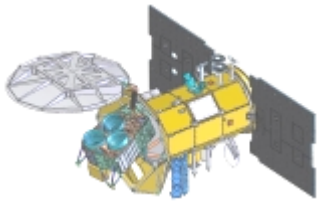


- Results from applying the following processes to the L1B2 data:
  - Resampling to a Map Projection
  - Earth Location Parameters Calculation
- It is desirable to use L1B2 as input, as the resampling process assume there is no superposition among neighour measurements at the input.
- Contains information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

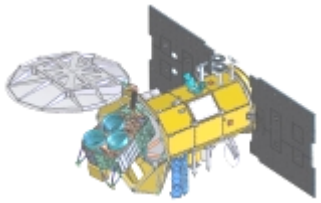
Product Performance



- 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 that 54 Km
- Spatial Accuracy is less than 10 Km

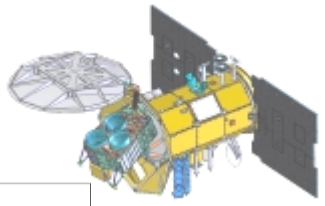


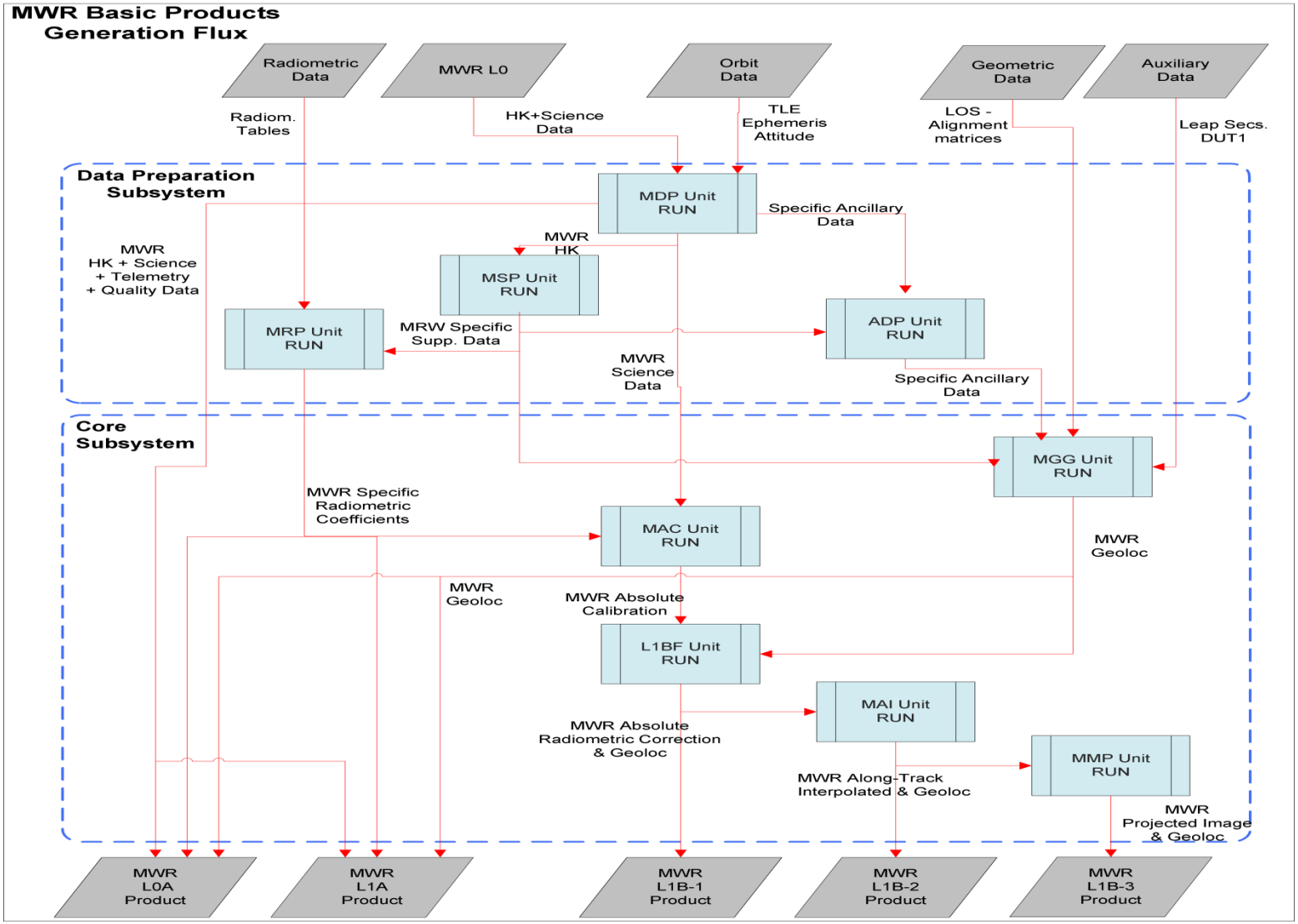
Processor:
Project, Architecture & Flow Diagram

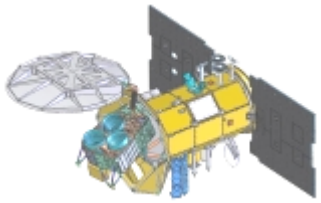


- The MWR processor is being developed as part of the MWP (MicroWave Processors) project at CONAE
- The MWP System is defined as a set of units which shall be part of CUSS (Conae User Segment Service)
- The development is guided by a software prototype developed with Python
- The testing will be supported 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.

Execution Flux - MWR

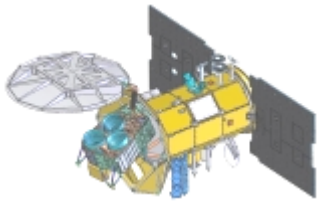






Simulation from Windat Data

Goals



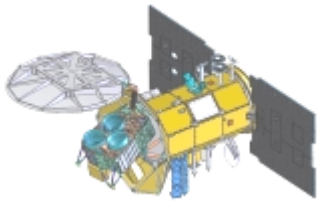
The first objetive of the simulation is to obtain a MWR L1A product using as input a calibrated Windsat Product.

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:

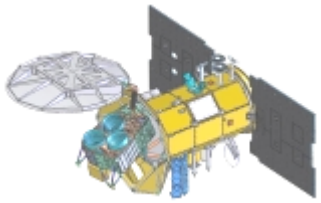
- Develop and test L2 Algorithms and Processors
- Develop and test L1 Prototypes and Processors

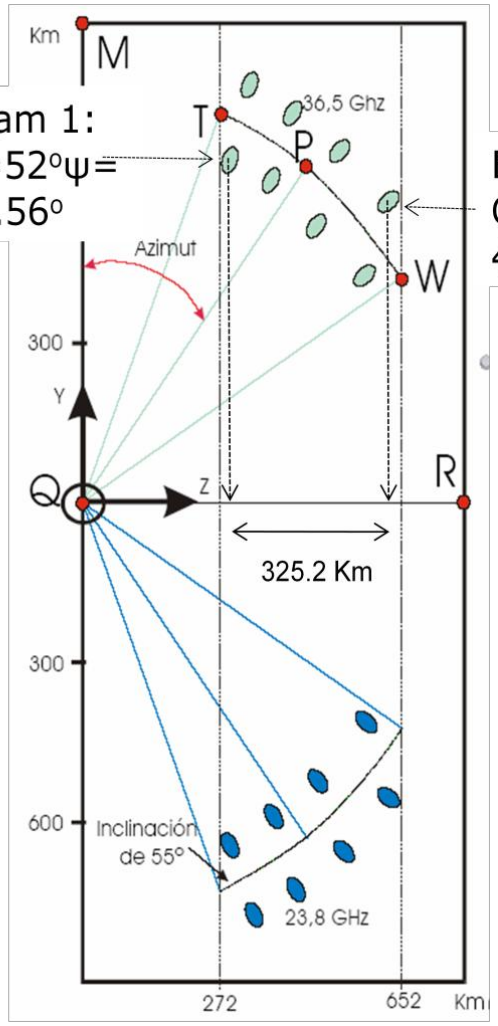
First Version

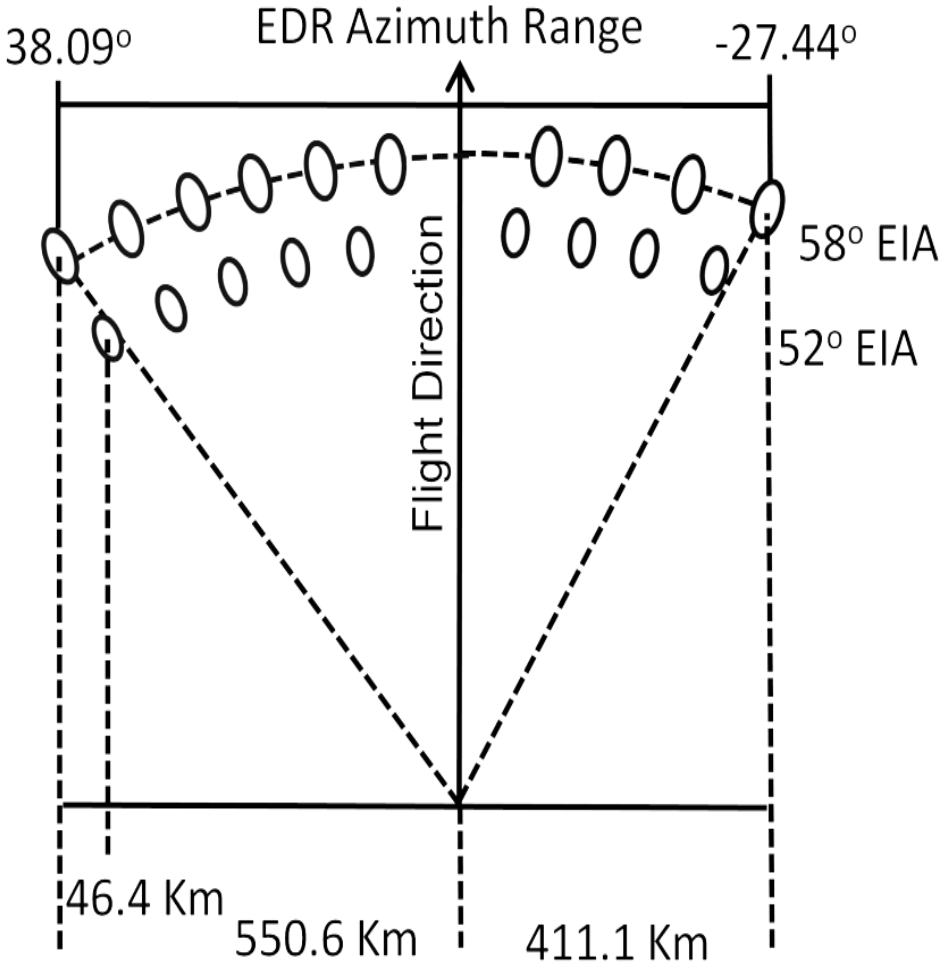


- Collaboration with the University of Central Florida in Orlando, Florida.
- Geometrically it is an intelligent resampler of the Windsat product. It doesn't generate an exact MWR Geometry.
- Radiometrically it is based on a conversion from Windsat Bt to MWR Bt, based on a comparison made using a Radiometric 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.

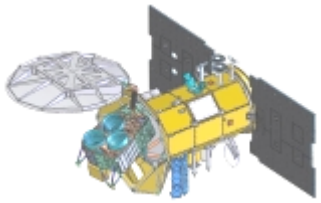
MWR Geometry and First Version Geometry

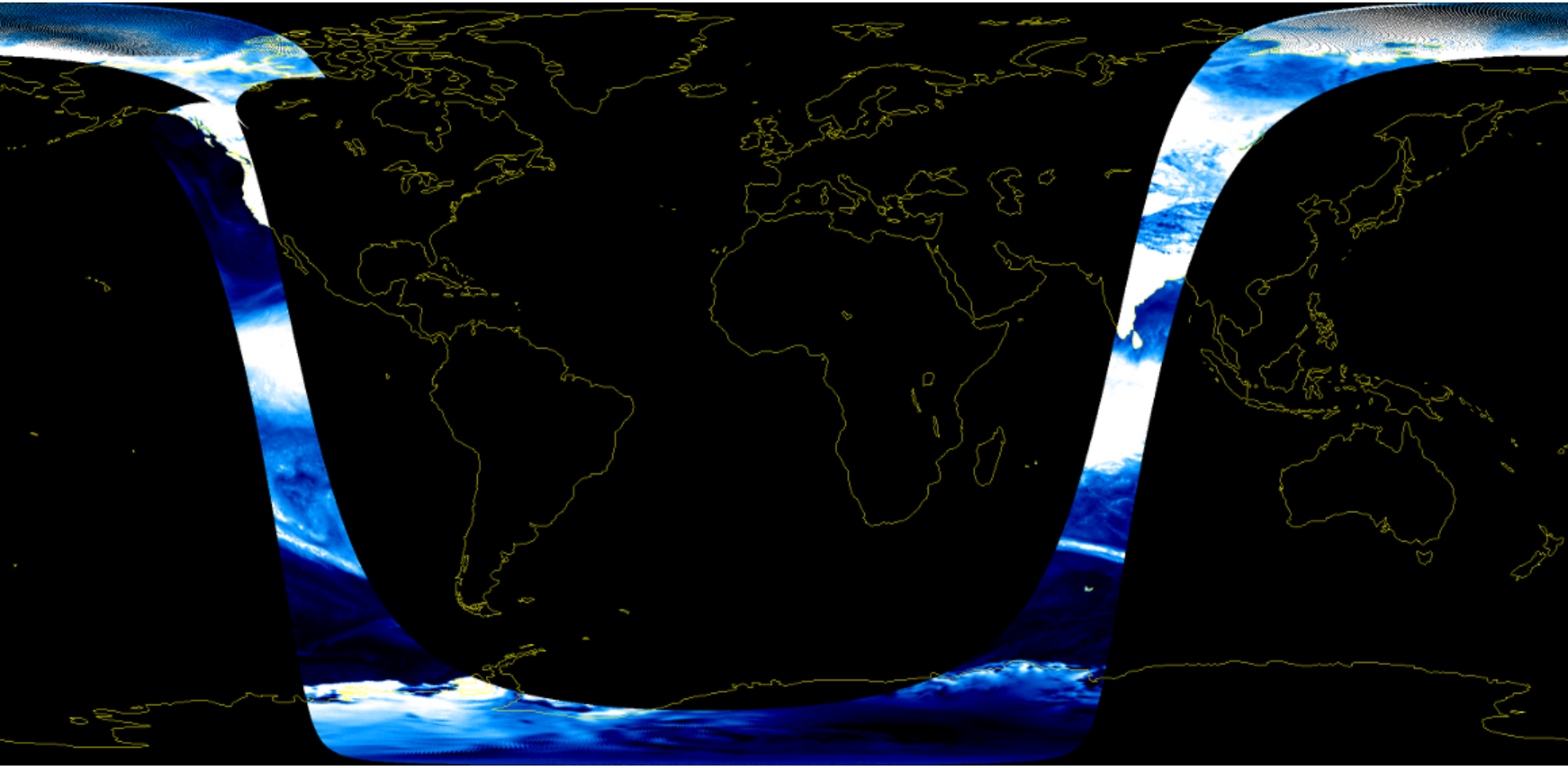






Windsat Orbit





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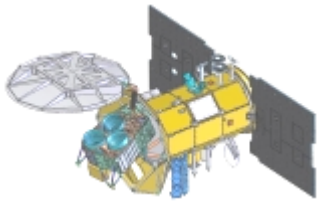
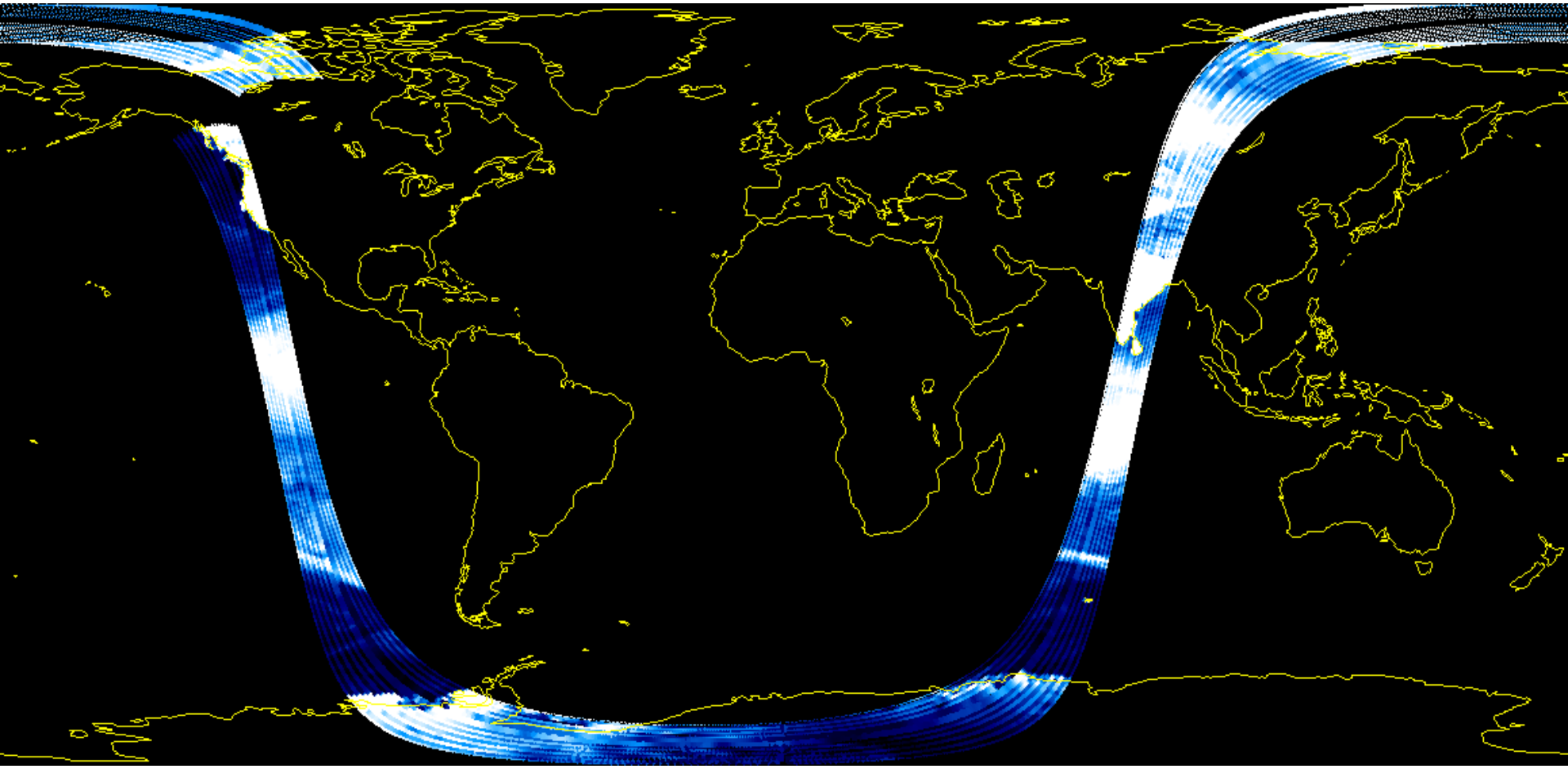
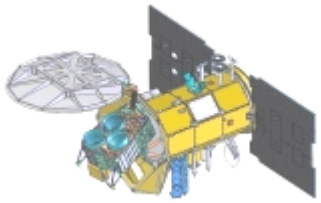
Simulated MWR Orbit with first version

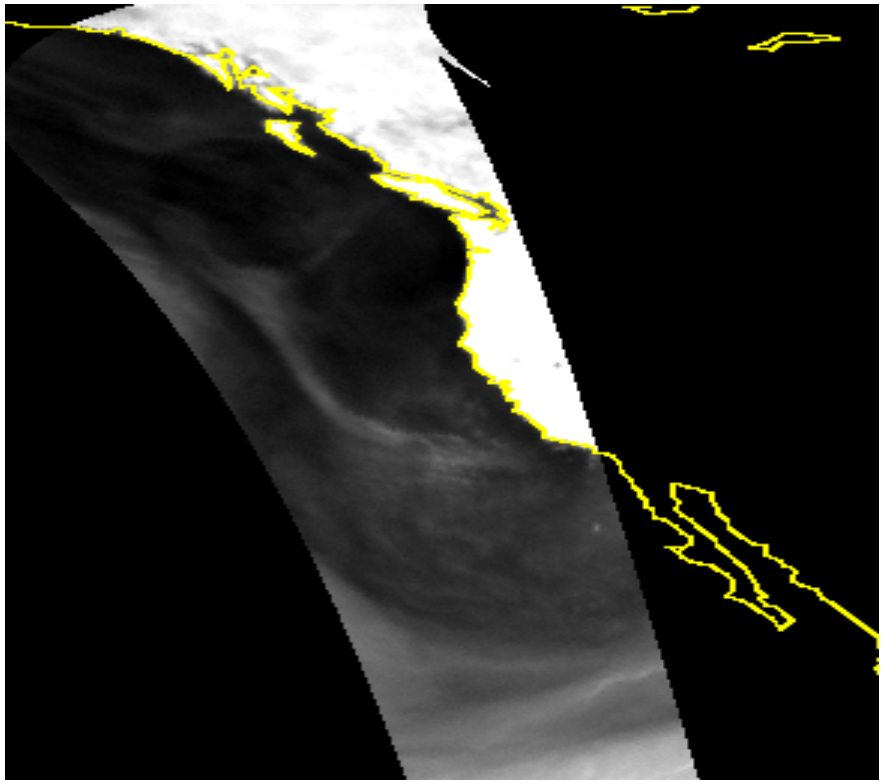




Footprint de MWR simulado a partir de Windsat (código MATLAB, tesis de Salman)

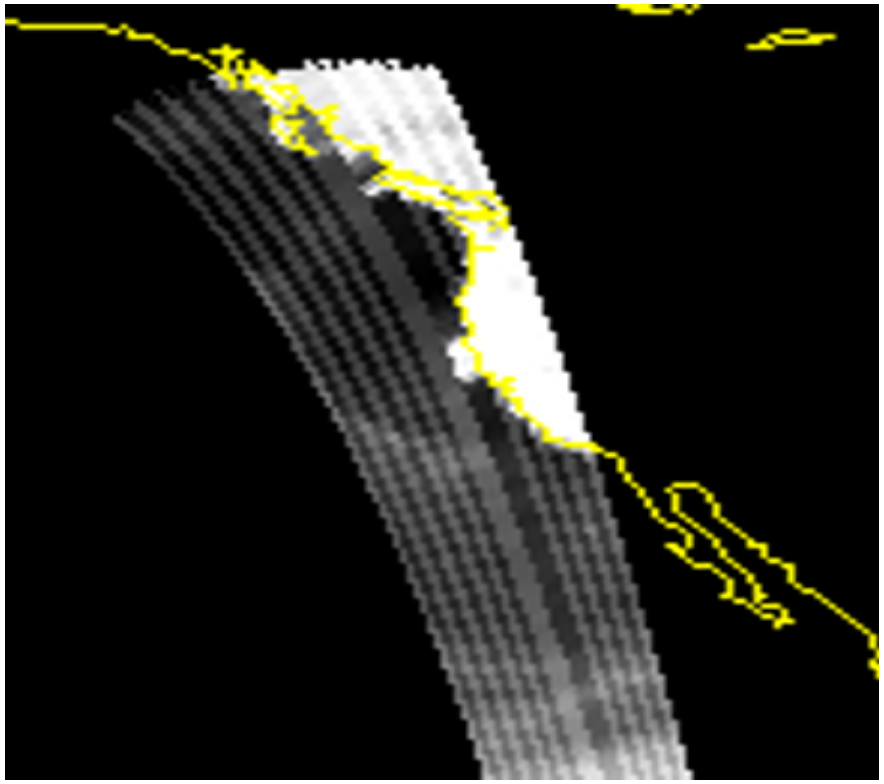
Zoom of products





Windsat Footprint Details.

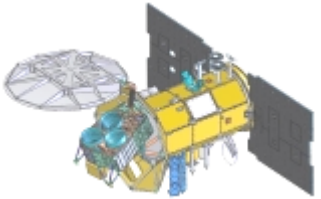
West Cost of EEUU is resalted in yellow.

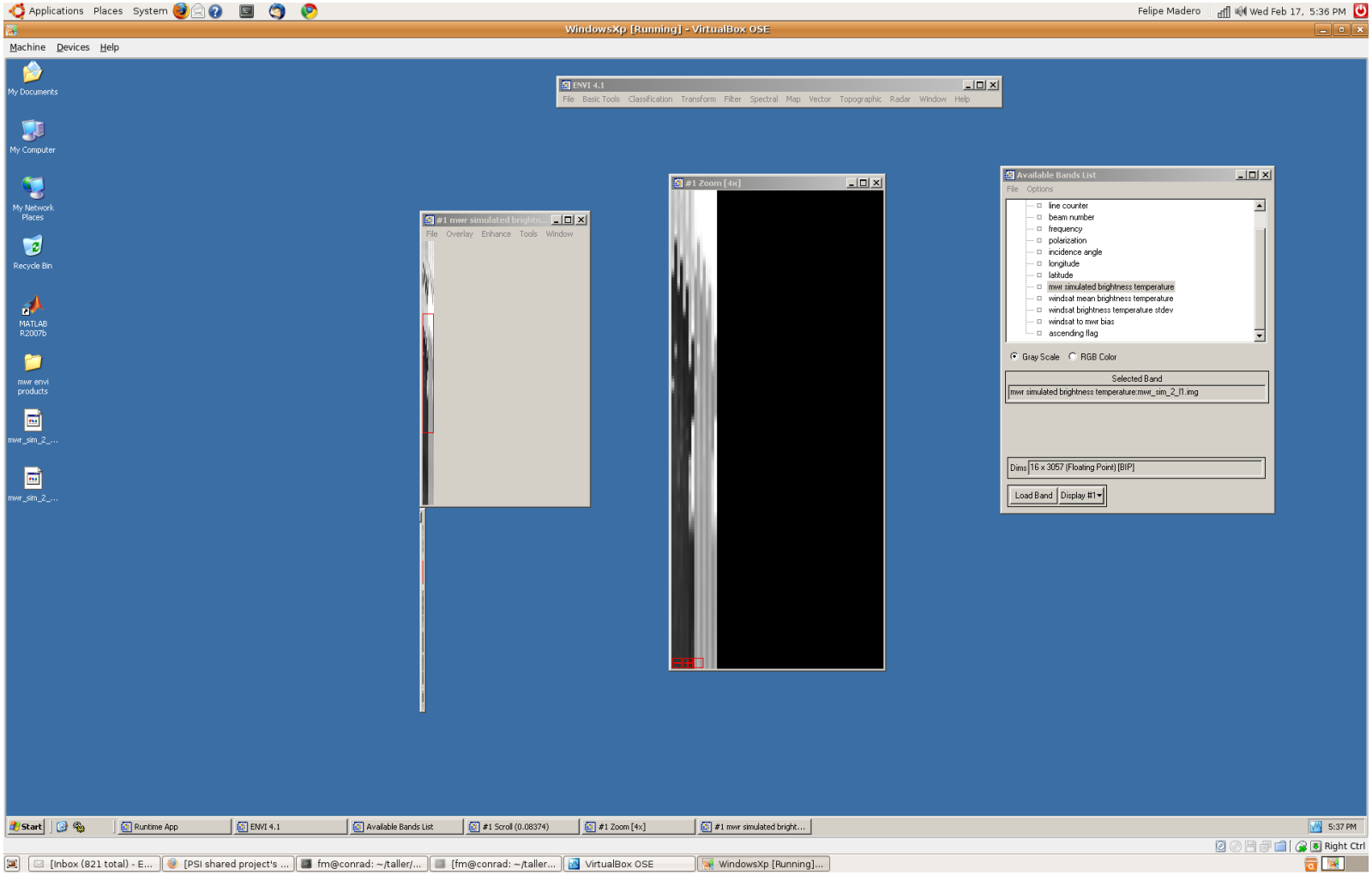


First version simulation details.

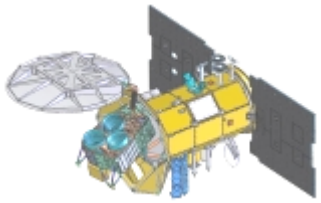
The different incidence angle of the horns results in the observed stripping.

Example ENVI Product



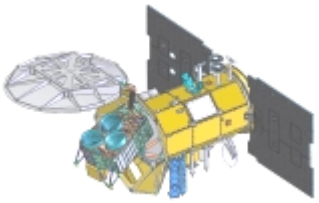


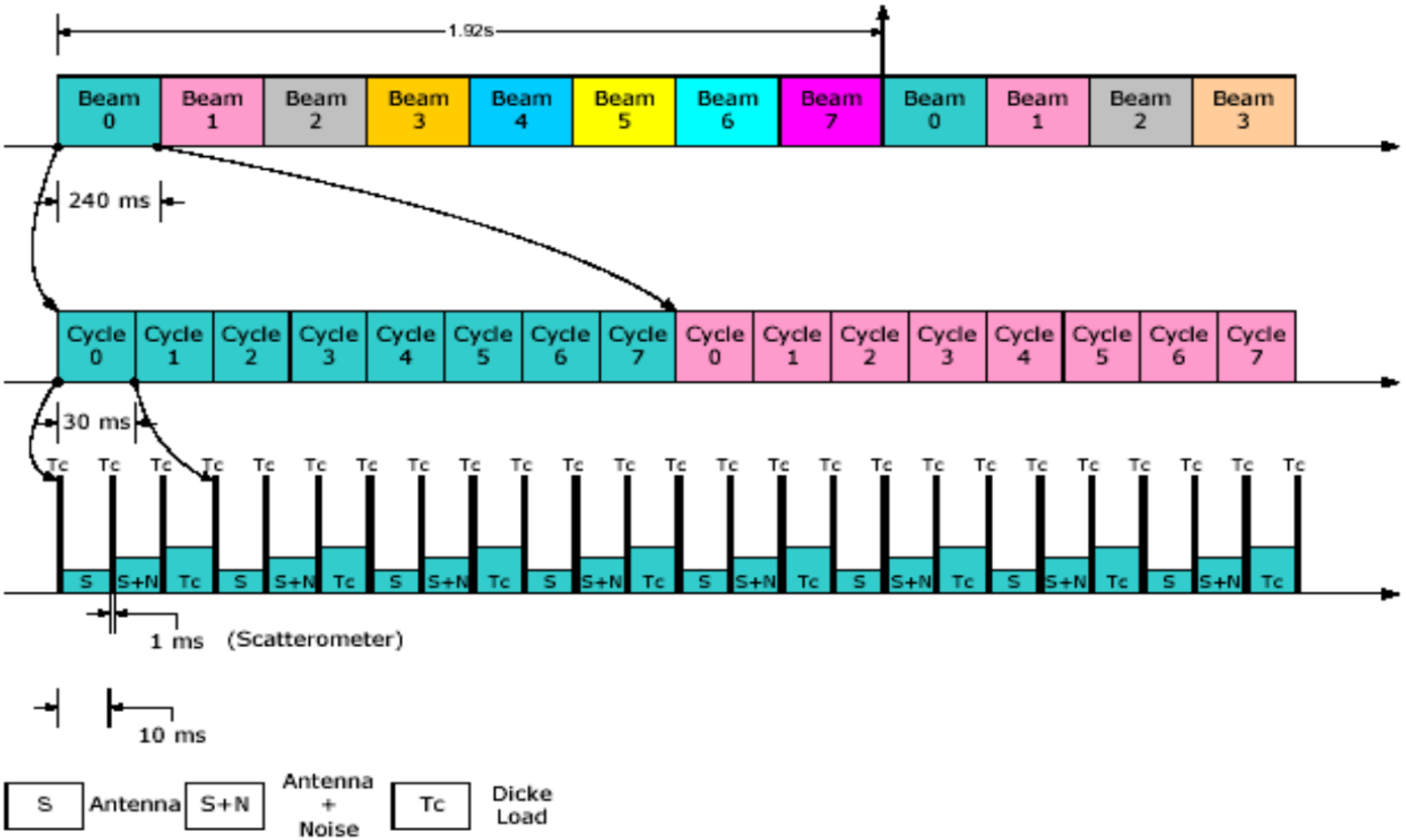
Second Version



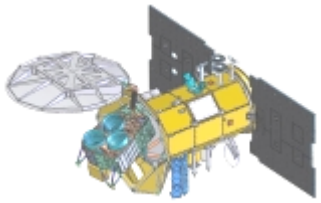
- CONAE Delopment. Made using a Python environment.
- Currently its execution is operational. Its results has already been submited to L2 science group.
- Geometrically, tries to simulate the MWR Geometry as exactly as posible.
- Radiometrically, uses a similar conversion from Winsat Bt to MWR Bt, based on the same Radiation Transfer Model. But also uses the measired antenna pattern as a basis for integration of Windat data.
- It also simulate more exactly the times associated to a MWR acquisiton: non null foorprint integration time, the 8 measurement cycles, the expected differences between acquisition and time tagging at platform.

Acquisiton times



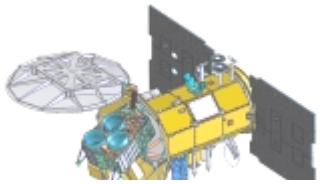


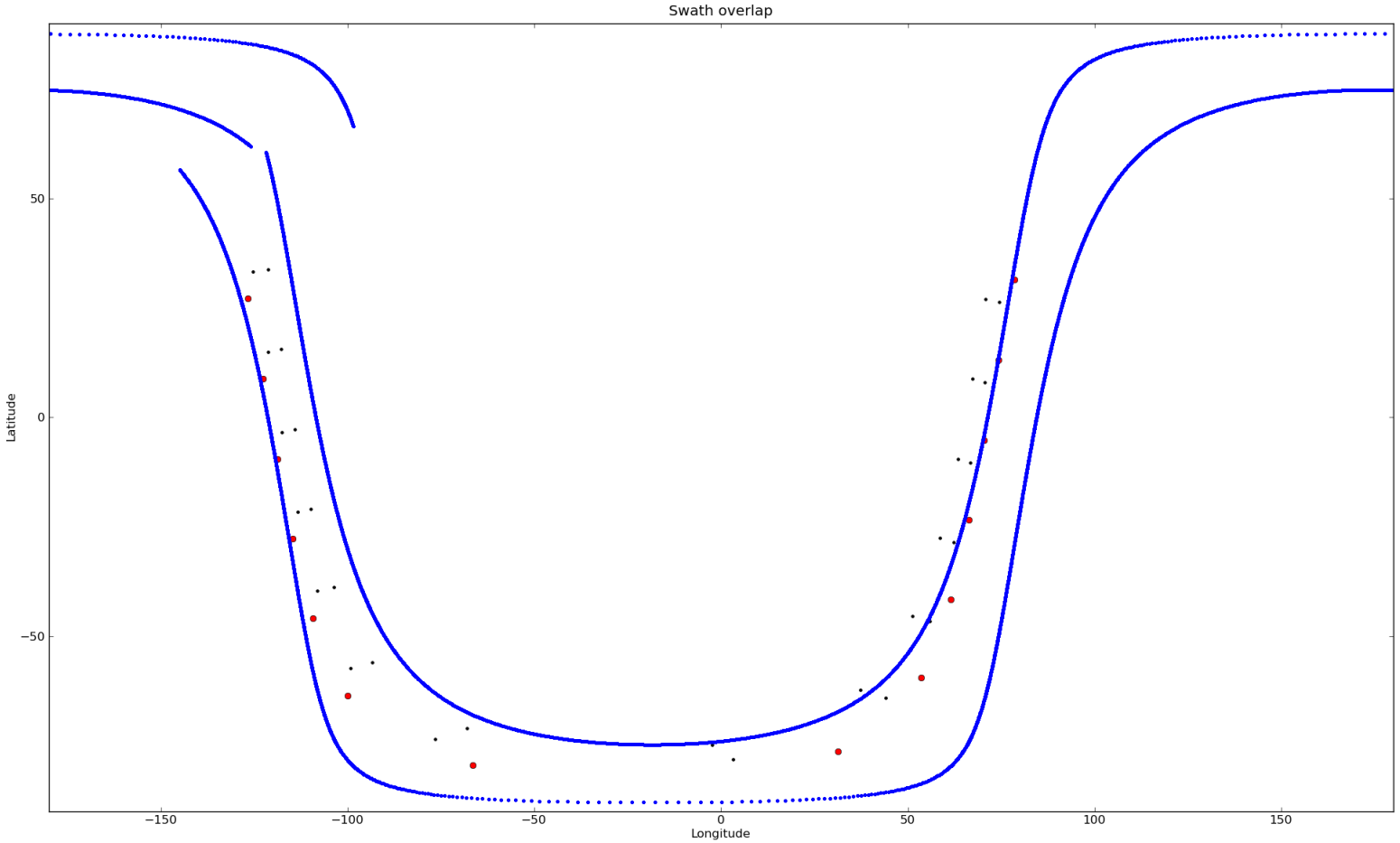
Orbit and Attitude Simulation



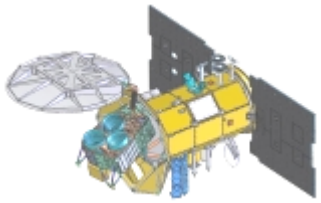
- The second version integrates the Windsat data based on a simulated SAC-D orbit, with simulated yaw steered attitude
- To get SAC-D state vectors, it is used a SGP4 propagator specifically translated to python for this project. It can also use externally generated state vectors. It remains to add position 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 appropiate SAC-D orbit that acquires over a given Windsat Product.

Simulated orbit over a Windsat product



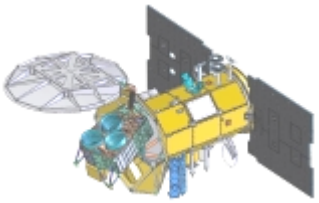


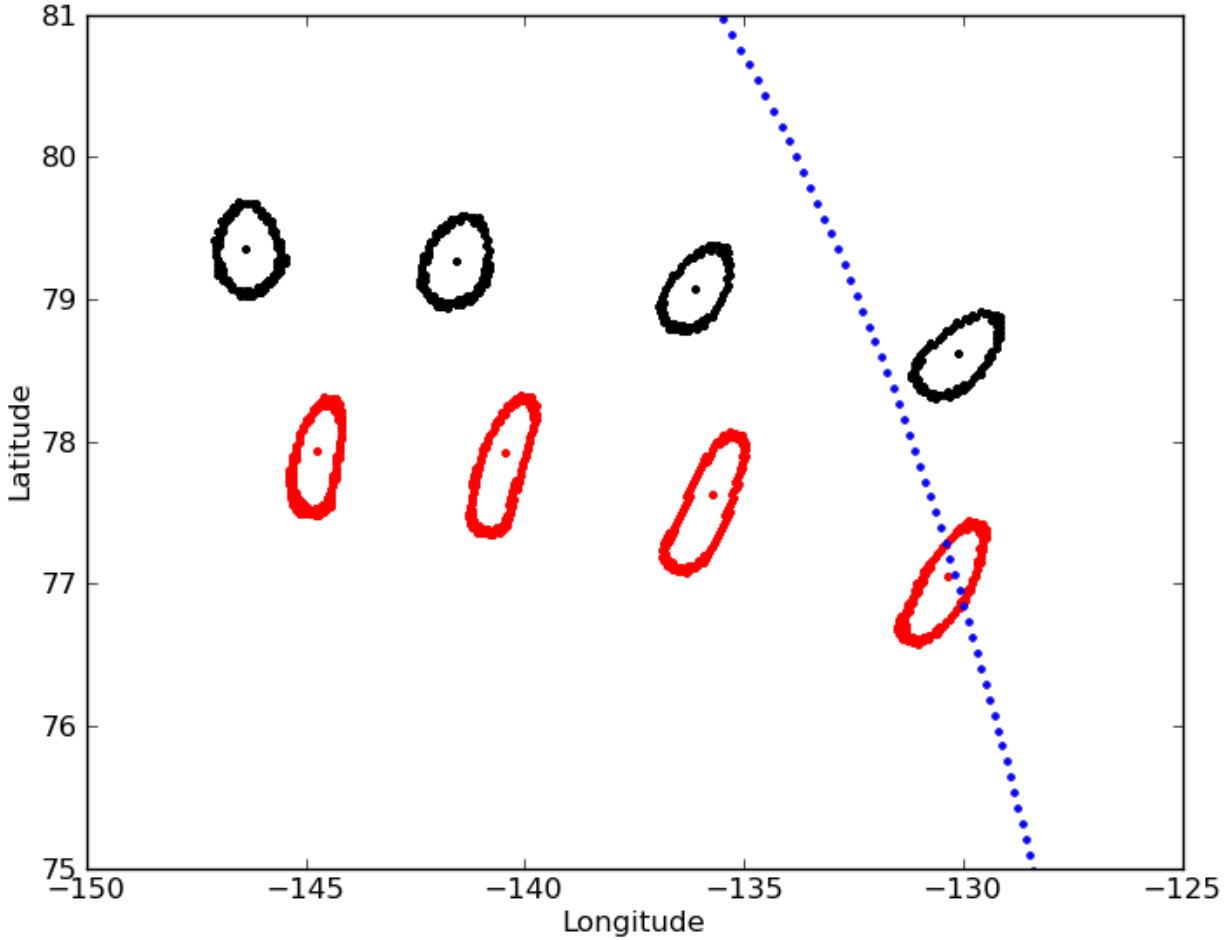
Radiometric and Geometric Parameters



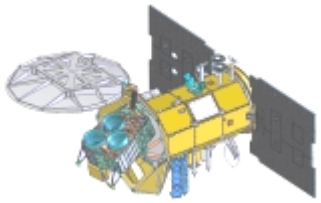
- The radiometric conversion coefficients are configurable in this version.
- The geometric parameters (line of sights, alignment matrices, antenna pattern (tipically -3dB) contours, are also configurable.
- We are currently using the best geometric parameters available, which resulted from antenna pattern measurements made at CONAE.

Example measured Line of sight and -3dB contour

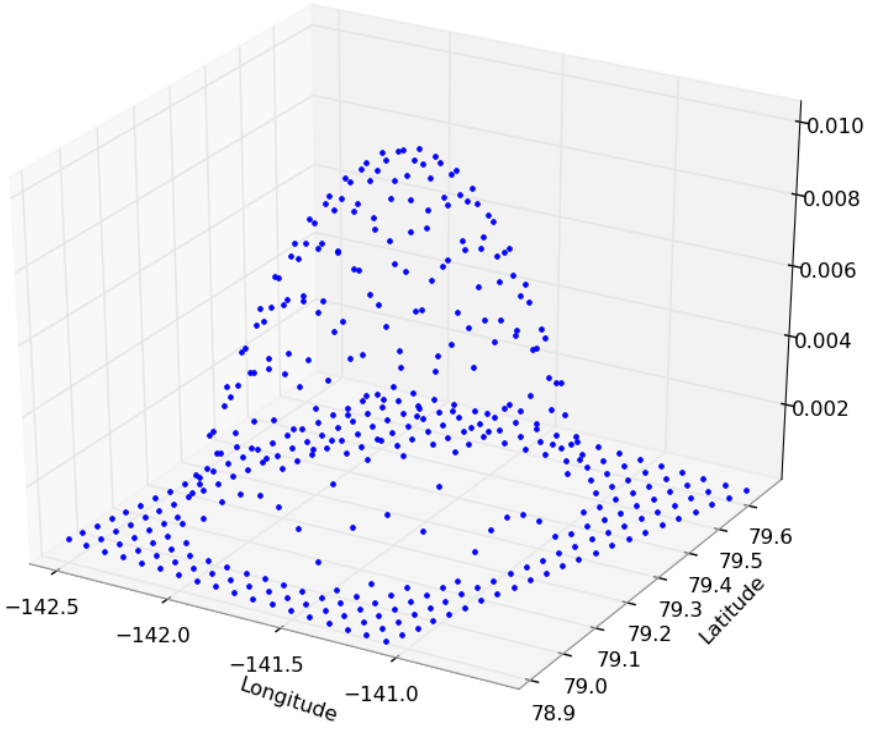




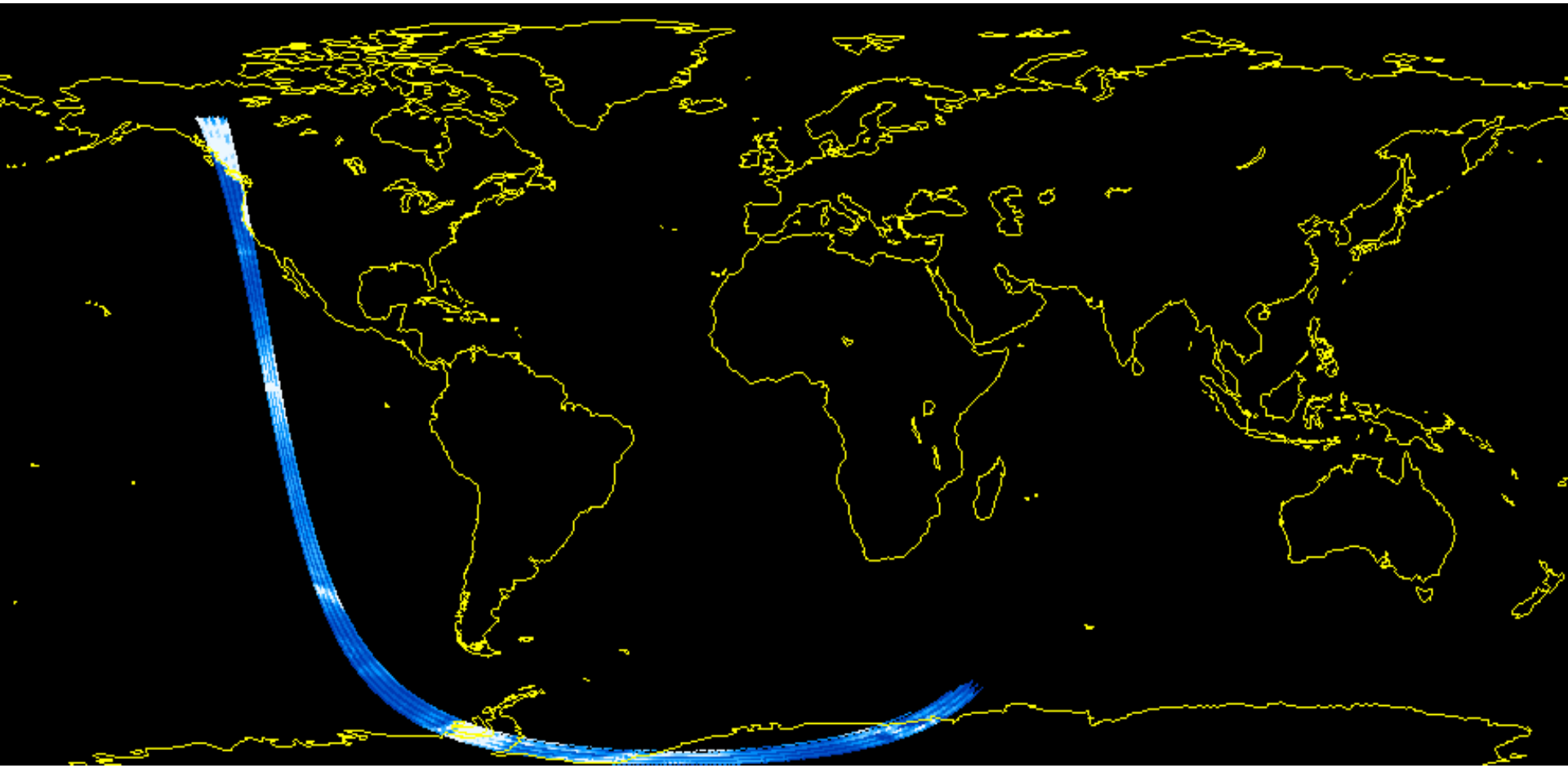
Antenna Pattern



- 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, …).

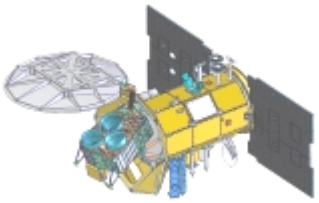


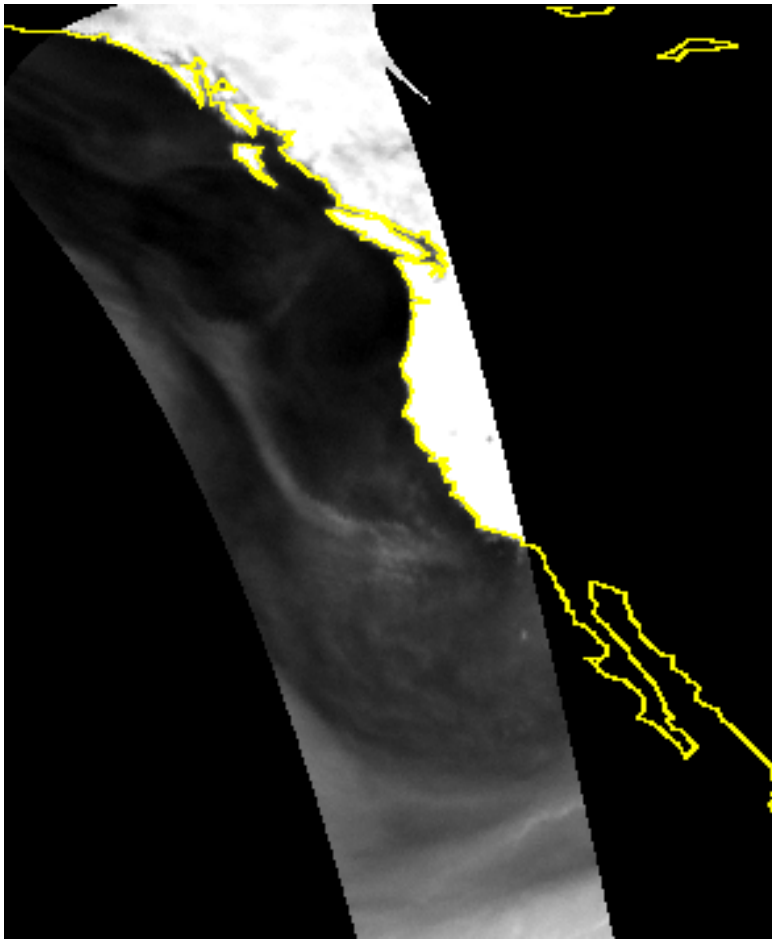
Simulated MWR Product

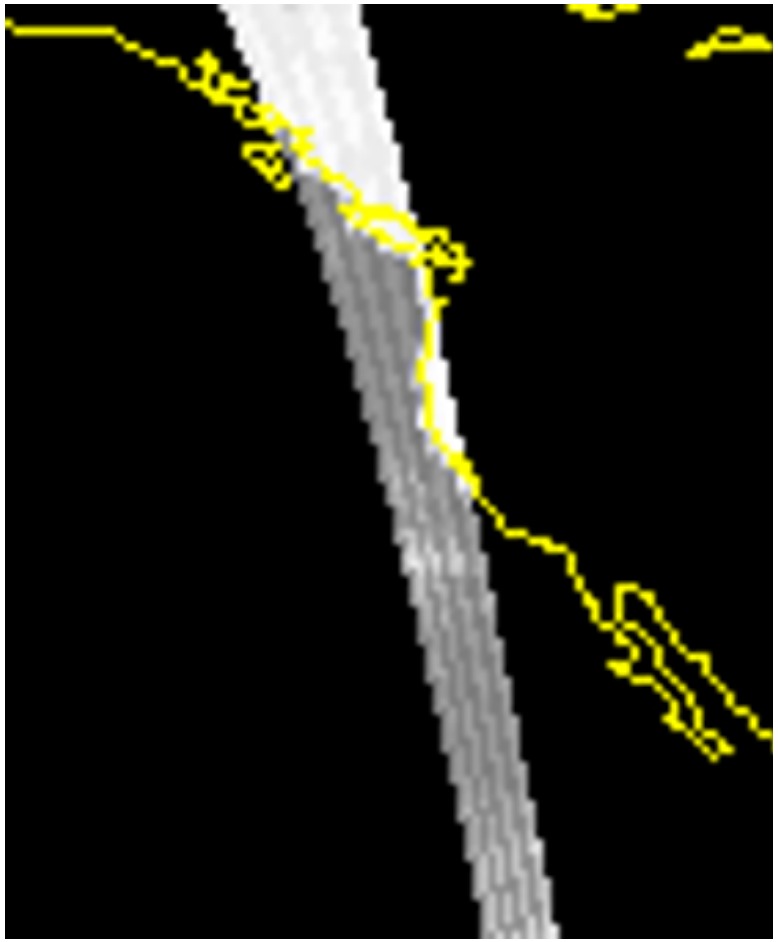


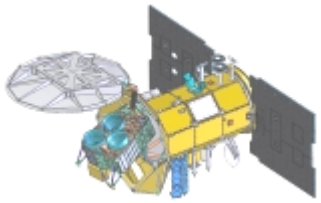
Results from Second Version of simulator

Zoom of Simulated MWR Product



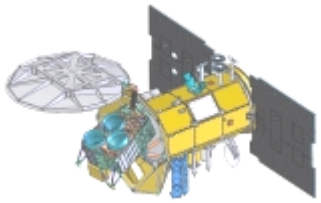






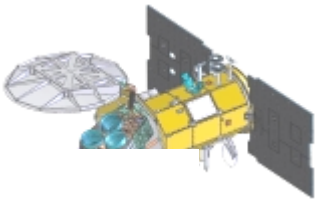
Science and Supplementary Data

BEAM

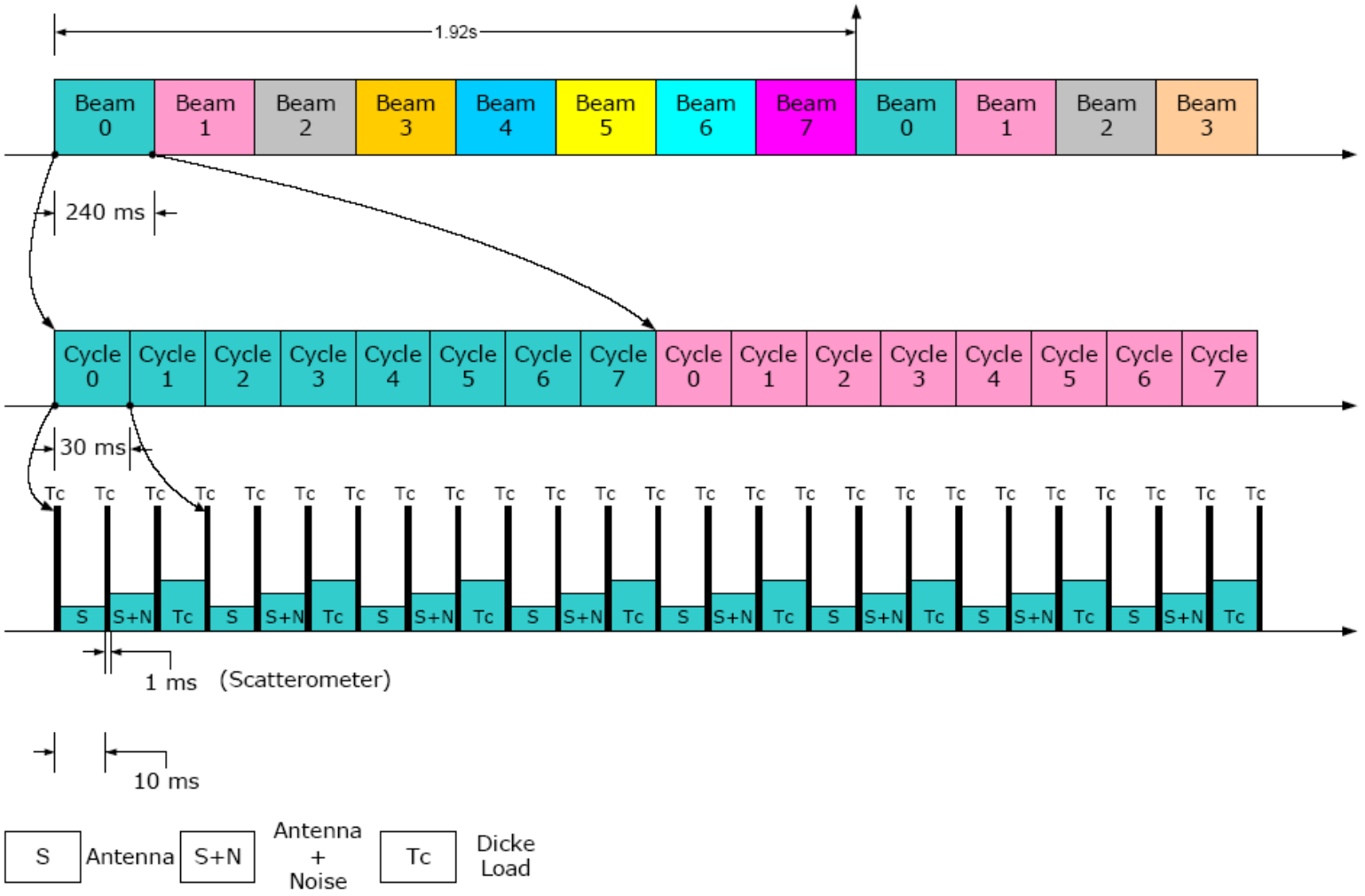


- The beam number indicates the horn that is beign measured for each radiometer. Both radiometers (23.8 GHz and 36.5 GHz) have 8 horns. The 23.8 horns has only V polarization. The 36.5 horns has both V and H polarization.
- The 36.5 Ghz radiometer has no receptors for +45 and -45 polarizations. The signals 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.

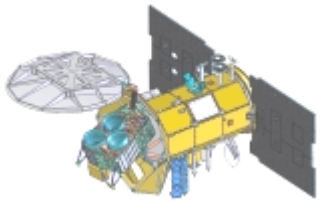
MWR Science Data



Microwave Radiometer - Timing Diagram



MWR Frame

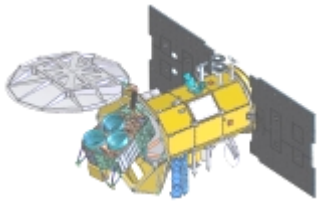


A MWR frame is compoused of the following information: science data associated to a beam plus HK data (Id, telemetry data, etc) for the time of acquisition of the beam.

Block	Number of items
1 - Id	1
2 - Science Data	15
3 - Telemetry Data	64
4 - Thermal Control Parameters	1
5 - CRC16 - CCITT	1

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).

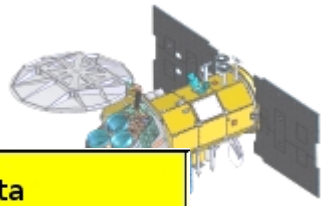
Id & Telemetry Data



- Id MSB ➔ Operation Mode (Mission, Stand Alone, Standby, Calibration, SACalibration & Diagnostic)
- Id LSB ➔ Horn.

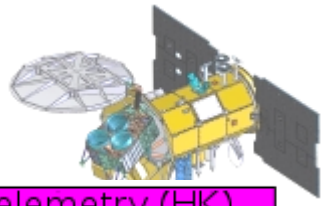
- In the telemetry data is contained the temperatures, voltages and currents of the different components of the instrument, plus temperatures of the container of MWR.
- The temperatures govern the behaviour of the radiometer. The transfer function of the receptor depends strongly on temperature changes.

Science Data



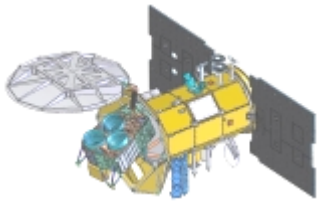
Science Data	Subsystem	Source	Data
SD-1	MWR – 36.5 GHz	Horizontal Polarization	**Signal**
SD-2	MWR – 36.5 GHz	Horizontal Polarization	**Signal+Noise**
SD-3	MWR – 36.5 GHz	Horizontal Polarization	**Load**
SD-4	MWR – 36.5 GHz	+45º Phase	**Signal**
SD-5	MWR – 36.5 GHz	+45º Phase	**Signal+Noise**
SD-6	MWR – 36.5 GHz	+45º Phase	**Load**
SD-7	MWR – 36.5 GHz	-45º Phase	**Signal**
SD-8	MWR – 36.5 GHz	-45º Phase	**Signal+Noise**
SD-9	MWR – 36.5 GHz	-45º Phase	**Load**
SD-10	MWR – 36.5 GHz	Vertical Polarization	**Signal**
SD-11	MWR – 36.5 GHz	Vertical Polarization	**Signal+Noise**
SD-12	MWR – 36.5 GHz	Vertical Polarization	**Load**
SD-13	MWR – 23.8 GHz	Horizontal Polarization	**Signal**
SD-14	MWR – 23.8 GHz	Horizontal Polarization	**Signal+Noise**
SD-15	MWR – 23.8 GHz	Horizontal Polarization	**Load**

Engineering Product - L0



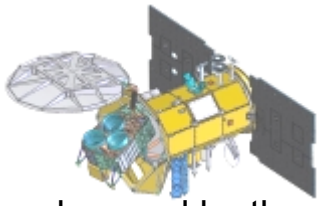
ID		Science Data															Telemetry (HK)
OP	Ant	36.5H			36.5+45			36.5-45			36.5V			23.8V			
		S	S+N	L	S	S+N	L	S	S+N	L	S	S+N	L	S	S+N	L	OBT, Temp, Tens ...
Beam0	0x05 0x01																
Beam1	0x05 0x02																
Beam2	0x05 0x03																
Beam3	0x05 0x04																
Beam4	0x05 0x05																
Beam5	0x05 0x06																
Beam6	0x05 0x07																
Beam7	0x05 0x08																
	0x05 0x01																
	0x05 0x02																
	0x05 0x03																
	0x05 0x04																
	0x05 0x05																
	0x05 0x06																
	0x05 0x07																
	0x05 0x08																

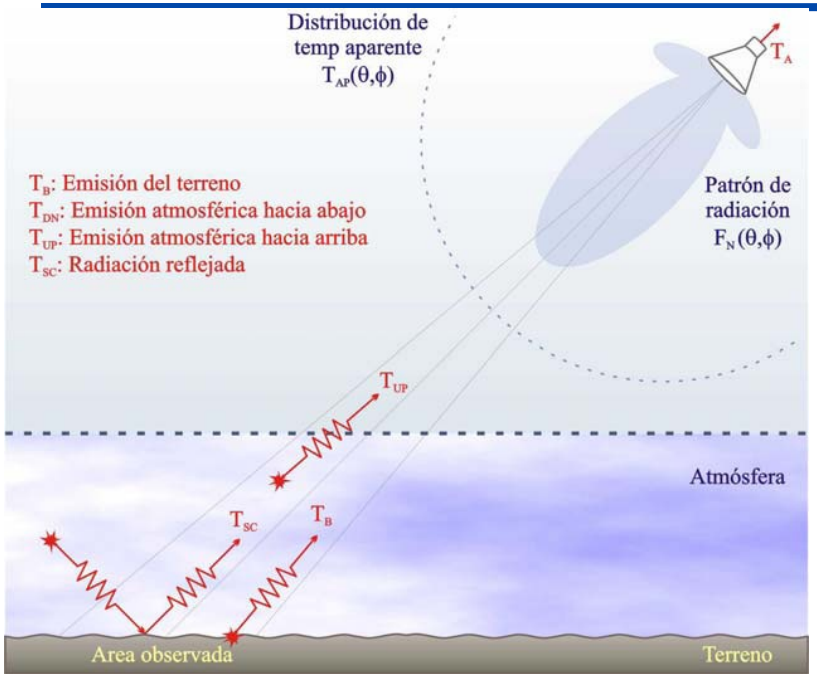
Identificador	Antena 23.8 GHz	Antena 36.5 GHz
0x01	Bocina 2	Bocina 1
0x02	Bocina 4	Bocina 3
0x03	Bocina 6	Bocina 5
0x04	Bocina 8	Bocina 7
0x05	Bocina 1	Bocina 2
0x06	Bocina 3	Bocina 4
0x07	Bocina 5	Bocina 6
0x08	Bocina 7	Bocina 8



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} : physic temperature of the antenna (horn).

T_A : apparent temperature as observed by the antenna.

T_A' : temperature transpased from the antenna to the receptor of the radiometer.

η_L : radiation eficiency of the antenna.

η_M : antenna main lobe efficiency (T_{ML})

$$T_A' = \eta_M \eta_L T_{ML} + \eta_L (1 - \eta_M) T_{SL} + (1 - \eta_L) T_{FA} \qquad -4-$$

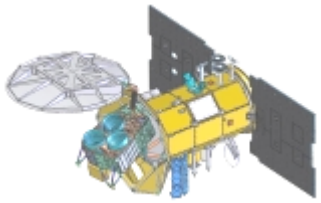
$$T_{ML} = \frac{1}{\eta_M \eta_L} T_A' - \frac{1 - \eta_M}{\eta_M} T_{SL} - \frac{1 - \eta_L}{\eta_M \eta_L} T_{FA} \qquad -5-$$

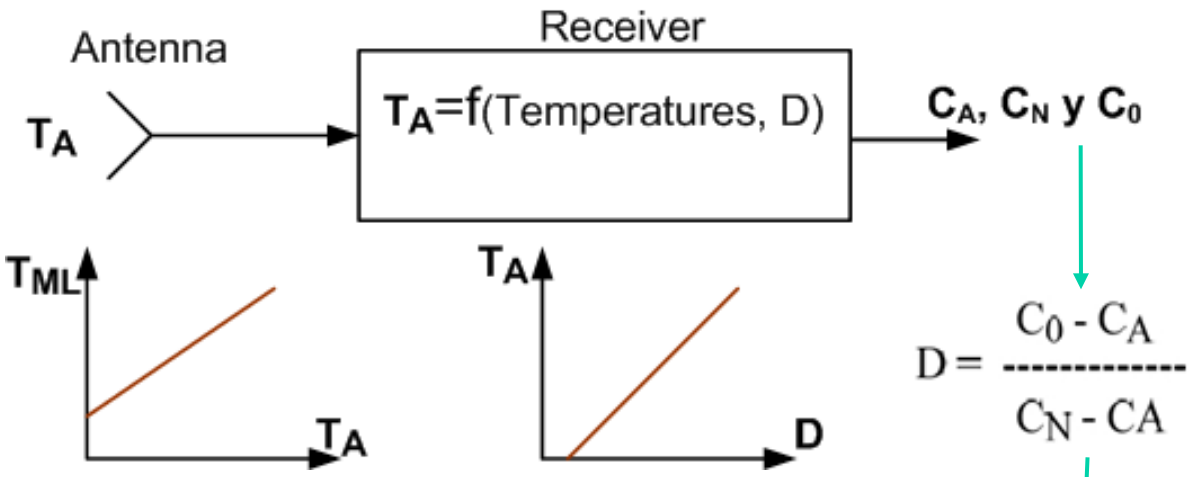
$$T_A' = \eta_L T_A + (1 - \eta_L) T_{FA} \qquad -6-$$

Si $\eta_L = 1 \rightarrow T_A' = T_A$ y

$T_A = \eta_M * T_{ML} + (1 - \eta_M) * T_{SL} \rightarrow T_{ML} = (1 / \eta_M) * T_A - ((1 - \eta_M)/ \eta_M) * T_{SL}$

Receptor Transfer Function





Receptor's transfer function:

$$T_A = \beta 0 + \beta 1.T_0 + \beta 2.TF_A + \beta 3.TF + (\beta 4.TF + \beta 5.T_N).D$$

$$T_A = off + gan * D$$

Antenna Pattern:

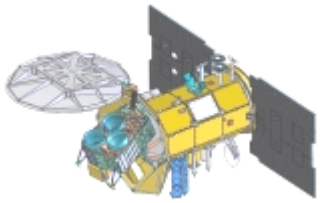
$$T_{ML} = \frac{T_A}{\eta_M} + \frac{\eta_M - 1}{\eta_M} * T_{SL} \quad ;\text{donde } T_{SL} \approx 2,7 \text{ K}$$

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

η_M : efficiency of the main lobe of the antenna.

Radiometric Calibration

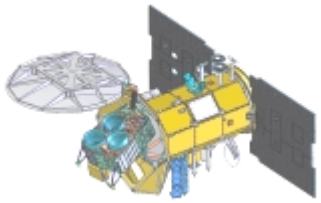


ID	Datas de Ciencia															Telemetria (HK)
OP Ant	36.5 H			36.5 +45			36.5 -45			36.5 V			23.8 V			OBT, Temp, Tens,...
	S	S+N	L	S	S+N	L	S	S+N	L	S	S+N	L	S	S+N	L	
0x05 0x01																
0x05 0x02																
0x05 0x03																
0x05 0x04																
0x05 0x05																
0x05 0x06																
0x05 0x07																
0x05 0x08																
0x05 0x01																
0x05 0x02																
0x05 0x03																
0x05 0x04																
0x05 0x05																
0x05 0x06																
0x05 0x07																
0x05 0x08																

Función de Transferencia del Receptor + Patrón de Antena

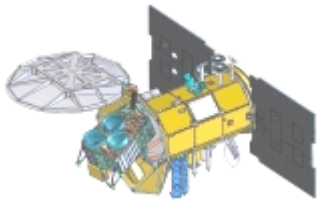
ID	Datas de Ciencia					Telemetria (HK)
OP Ant	36.5 H	36.5 +45	36.5 -45	36.5 V	23.8 V	OBT, Temp, Tens,...
	T_{ML}	T_{ML}	T_{ML}	T_{ML}	T_{ML}	
0x05 0x01						
0x05 0x02						
0x05 0x03						
0x05 0x04						
0x05 0x05						
0x05 0x06						
0x05 0x07						
0x05 0x08						
0x05 0x01						

Identificador	Antena 23.8 GHz	Antena 36.5 GHz
0x01	Bocina 2	Bocina 1
0x02	Bocina 4	Bocina 3
0x03	Bocina 6	Bocina 5
0x04	Bocina 8	Bocina 7
0x05	Bocina 1	Bocina 2
0x06	Bocina 3	Bocina 4
0x07	Bocina 5	Bocina 6
0x08	Bocina 7	Bocina 8



Geometric Corrections

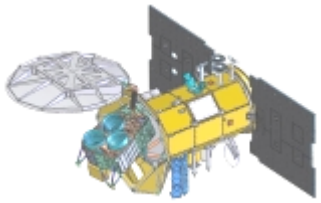
Goals



The objectives of the corrections are:

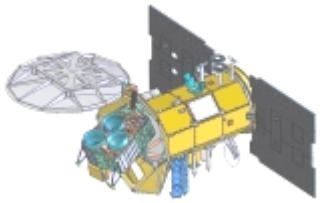
- To be able to obtain the latitude, longitude, and other earth location information, for each pixel in an image, with the best accuracy at hand
- Te be able to interpolate the data along track, so as to reduce overlap and improve geometric resolution, with no reduction on the radiometric quality.
-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

Earth Location Parameters

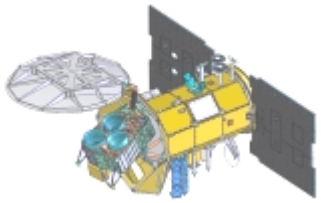


- Plenty earth location parameters are provided: latitude, longitude, range to spacecraft, azimuth and zenith angles to spacecraft, sun, and moon.
- Processor inputs (attitude and ephemeris data) are validated, and when suitable, interpolated.
- Using geometric auxiliar data, such as line of sight vectors 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 to a Map Projection

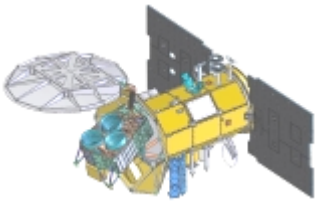


- Resampling based on a partition of the input space in cells (using the grid of the geoloc), and calculating forward and reverse transformations for each cell, between geodetic coordinates and projected coordinates.
- Transformations calculated using Singular Value Decomposition methods.
- Interpolation currently using NN, Bilinear and CC.
- Currently studying alternatives for doing along track interpolation.

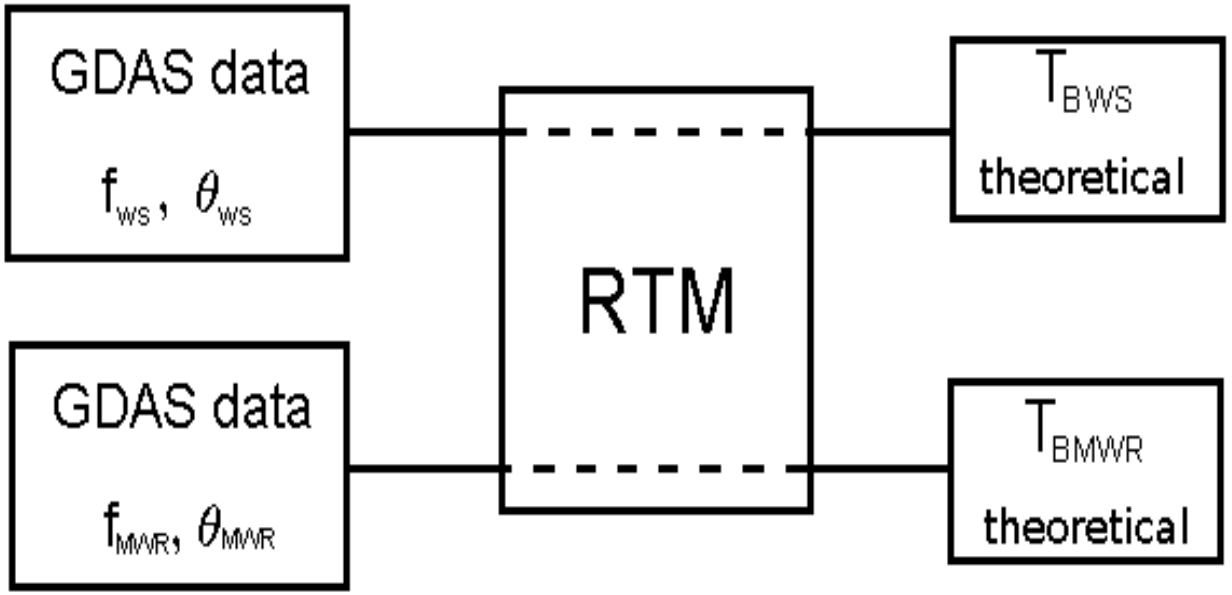


Cross Calibration using Windsat

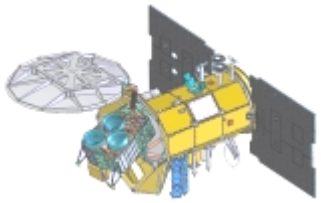
T_b Normalization



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



T_b Normalization



Calculate theoretical T_{bMWR} for geophysical parameters (1° box)

$T_{bMWR}^{theoretical}$ (f_{MWR}, θ_{MWR}, ws, SST, wv, CLW)

Frequency = 23.8 & 36.5 GHz

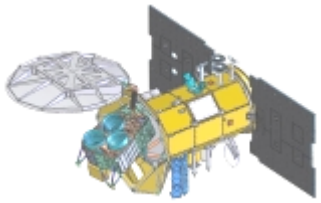
Incidence Angle = 52˚ & 58˚

Calculate theoretical T_{bWS} for geophysical parameters (1° box)

$T_{bWS}^{theoretical}$ (f_{WS},Θ_{WS}, ws, SST, wv, CLW)

Frequency = 23.8 & 37 GHz

Incidence Angle = 53˚



$T_{bMWR}^{measured}$ and $T_{bWS}^{measured}$ (calibrated)

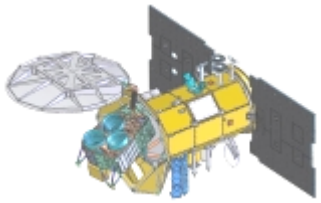
Run RTM in order to:

1) 23.8 GHz: (v, f_1, θ_1)
   (v, f_1, θ_2)
1) 36.5 GHz: (v, f_2, θ_1)
   (h, f_2, θ_1)
   (v, f_2, θ_2)
   (h, f_2, θ_2)

$\Rightarrow$ We get $T_{bMWR}^{theoretic}$ y $T_{bWS}^{theoretic}$ (using GDAS data)

$$\Delta T_b^{theoretic} = T_{bMWR}^{theoretic} - T_{bWS}^{theoretic}$$

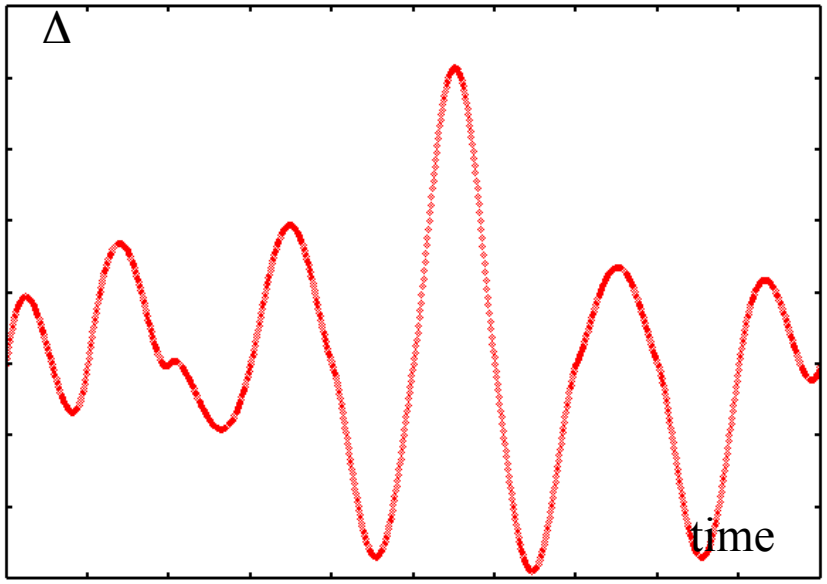
$$\Rightarrow T_{bMWR}^{predicted} = T_{bWS}^{measured} + \Delta T_b^{theoretic}$$

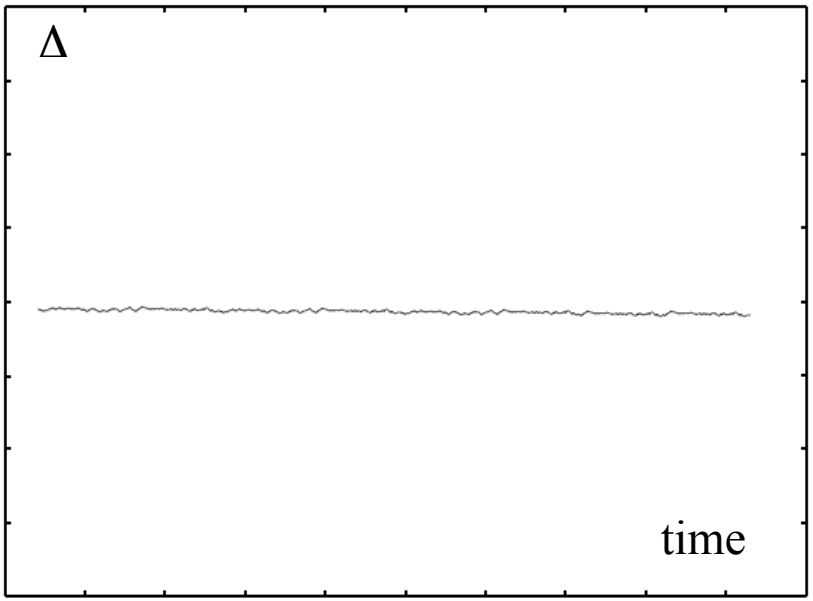


Then:

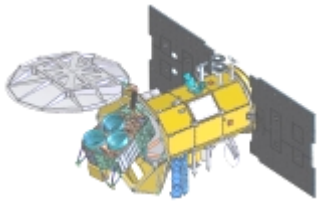
$\Delta = \text{Bias}_{MWR} = T_{bMWR}^{measured} - T_{bMWR}^{predicted}$

So, Δ vs time:



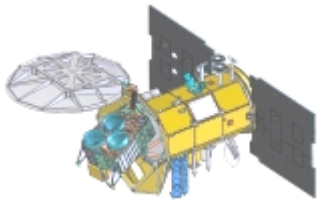


Variations with time implies corrections, if is constant or varies a little implies no corrections



Product Format

Product formats

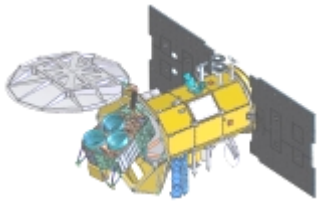


- Processor output: XML files.

- 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 contect 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.

END



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