On the stability of Amazon rainforest backscattering during the ERS-2 Scatterometer mission lifetime

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Abstract

This paper reports the result obtained on the analysis of Amazon backscattering signal during the eight years of ERS-2 Scatterometer mission. To assess the stability of the reference target is necessary to take into account some "spectral properties" of the gamma nought time series and to compensate for mission events that have impacted the data calibration as the loss of the gyroscopes from 17th January 2001 onwards, or the instrument calibration performances as the on board swaps of the instrument calibration sub-system in August 1996.

1. Introduction

The Amazon rainforest at the working frequency used in remote sensing satellites and many airborne systems which operate at X, C and L-band, acts as pure volume scatterer over a wide range of incidence angle. The transmitted signal is equally scattered in all directions and most of the scattered radiation is from the crown area and tends to have a slow incidence angle variation that can be characterized by the equation:

$$\gamma^0_{Linear} = \frac{\sigma^0_{linear}}{\cos\theta} \tag{1}$$

The backscattered signal σ^0_{linear} depends only by the surface effectively seen by the antenna via the incidence angle θ. That dependency can be removed with the simple model described in Eq. 1 and the derived Gamma nought figure can be used to refine the antenna pattern while the satellite is in orbit and to monitor the calibration performances of Spaceborn system. For that reason the Amazon rainforest has been chosen as a reference natural target in some Earth Observation mission like ERS-1 and ERS-2, J-ERS-1, and RADARSAT. The large extension of the rainforest, its stability and its isotropic property allow to compare in one satellite pass the signal from the entire swath of the antenna.

The gamma nought measurements over the Amazon rainforest can also be used to investigate the stability of the reference target as done in [1]. Scope of this paper is to deeply investigate the Gamma nought time series obtained by ERS-2 Scatterometer instrument to characterize the stability of the Amazon rainforest signal at C-band

2. The ERS-2 Scatterometer Gamma Nought time series

Since the beginning of the ERS-2 Scatterometer mission in April 1995 the Amazon rainforest has been used to monitor the relative calibration and the antenna pattern profiles of the instrument by ESA [2]. The test area used is located between 2.5 degrees North and 5.0 degrees South in latitude and 60.5 degrees West and 70.0 degrees West in longitude For that reason a long data time series of Gamma nought measurement for each Scatterometer antenna and for ascending (night) and descending (day) passes is available for investigation.

From Eq. 1 the gamma nought measurement is independent from the incidence angle, and therefore a sharp peak characterizes its histogram. A time-series of the gamma nought can be produced by computation the position of the histogram's peak. That parameter can be computed by fitting the gamma nought histogram with a normal distribution added to a second order polynomial:

$$F(x) = A_0 \exp\left(\frac{x - A_1}{A_2}\right)^2 + A_3 + A_4 x + A_5 x^2 \tag{2}$$

The five parameters of the model are computed using a non-linear least square method called "gradient expansion". The position of the peak is given by the maximum of Eq 2. The Gamma nought time series is defined as the evolution of that peak. For the ERS-2 Scatterometer calibration monitoring purpose the histograms are computed weekly (from Monday to Sunday) with a resolution of 0.02 dB within the ESA Product Control Service.

The Gamma nought time series compute with that technique is shown in Fig. 1 from January 1996 up to now [3].

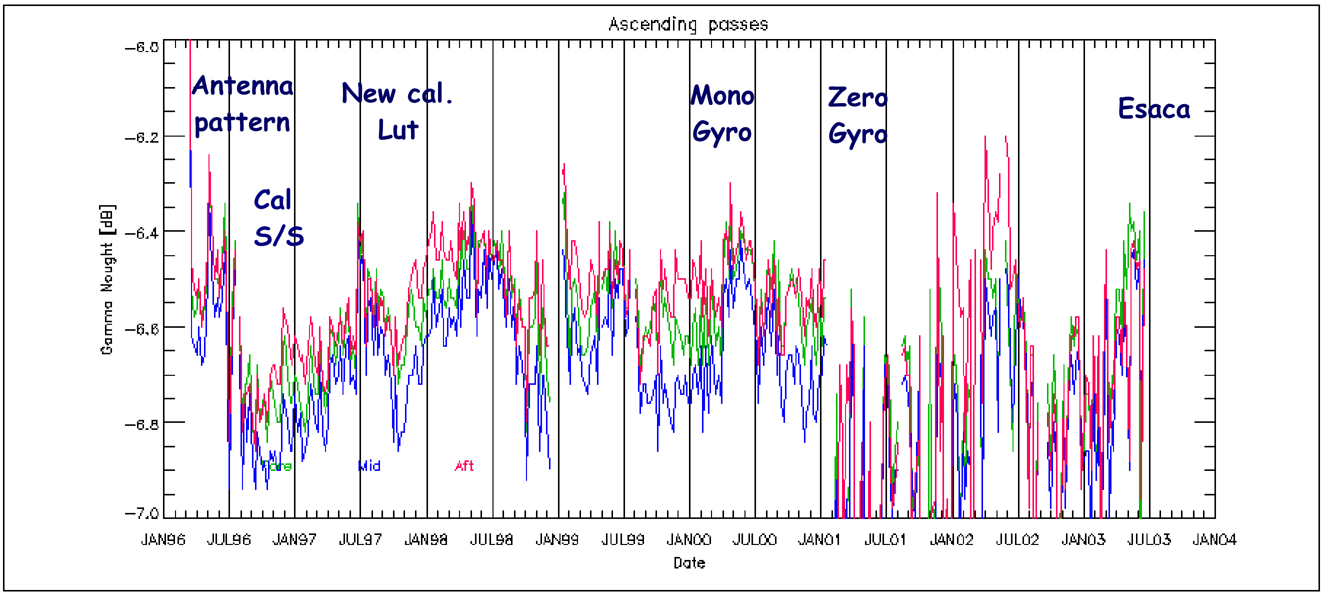


Fig. 1. ERS-2 Scatterometer gamma nought time series. Ascending passes.

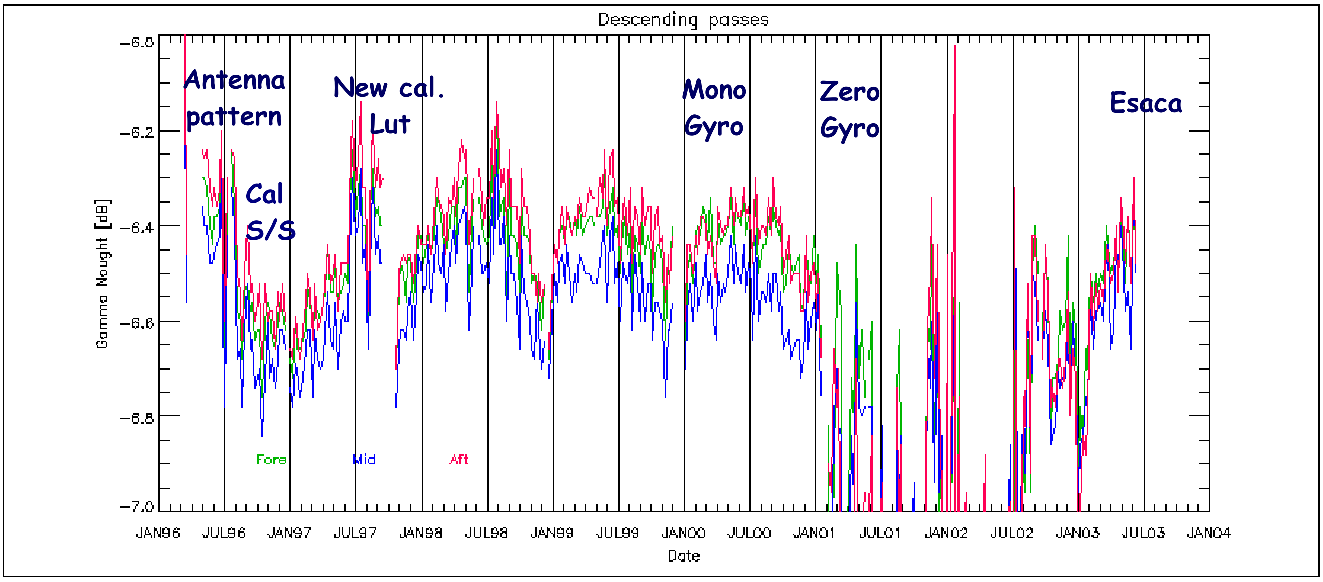


Fig. 2. ERS-2 Scatterometer gamma nought time series. Descending passes.

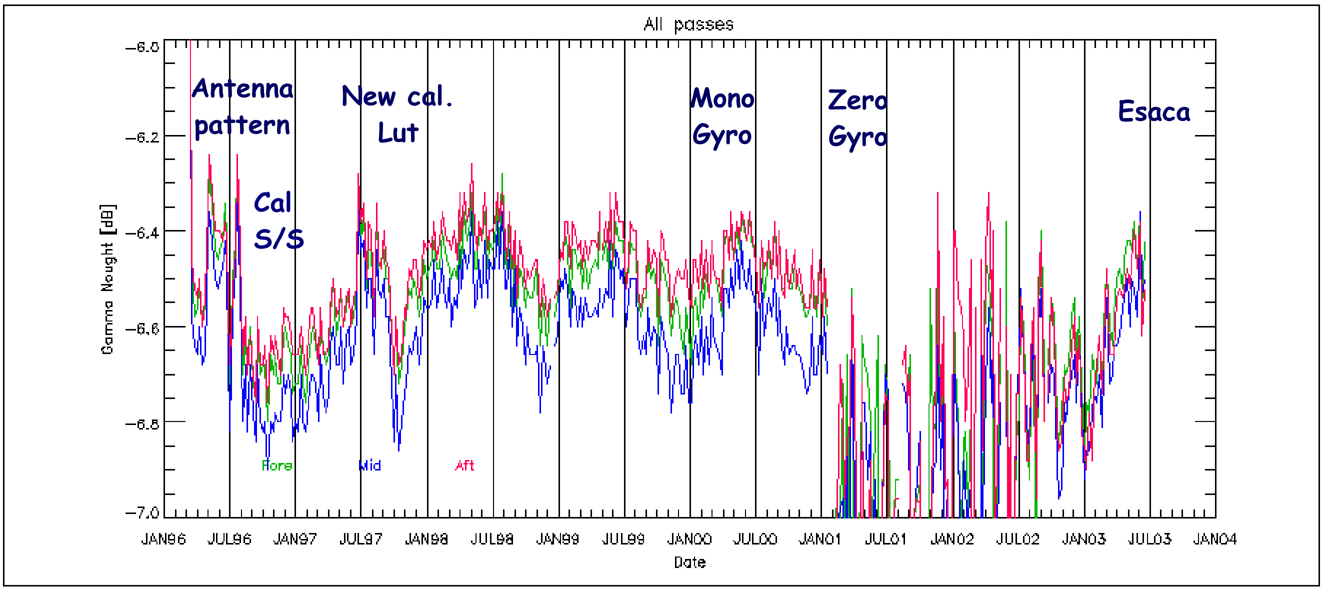


Fig. 3. ERS-2 Scatterometer gamma nought time series. All passes.

To investigate the stability of the reference target, it is necessary to assure that the changes on instrument or satellite occurred during a space mission lifetime are properly corrected and compensated for. The events that had an impact in the gamma nought time series evolution and related corrective actions are detailed in Table 1. As reported in Table 1 up to now, only data acquired between mid March 1996 and January 2001 can be used to assess the temporal stability of the Amazon rain forest. That 5-years period can be further extended until June 2003 by re-processing data acquired in Zero Gyro Mode with the new ESACA processor (ERS Scatterometer Attitude Corrected Algorithm). ESACA is able to re-calibrate the Scatterometer data in ZGM as shown in Fig.1. For a detailed description of the impact of ZGM on Scatterometer data see [4], for ESACA see [5],[6].

Table 1 ERS-2 Scatterometer mission events and impact on Gamma nought time series

Event	Date	Description	Impact on gamma nought	Recovery actions
Commissioning phase	Launch April 1995 Mid March 1996	Instrument calibration and in-orbit antenna patter	Calibrated Gamma nought from mid March 1996 onwards	Re-processing of Scatterometer data with the new ESACA algorithm
New Cal S/S	August 6th 1996	Failure of the calibration sub-system side A. Switch to side-B	The redundancy device side-B caused a change in the absolute calibration of 0.2 dB	Available Gamma nought from August 6th 1996 to June 19th 1997 shall be increased by 0.2 dB
New Lut	June 19th 1997	Added 0.2 dB for the calibration constant in the ground processor (new calibration LUT)	Calibrated Gamma nought	N/a
ZGM com.	January 17th 2001	Start of the Zero Gyro Mode commissioning phase 5 of 6 gyros on-board were out of order or very noise and for that reason the satellite is piloted without gyros.	Satellite de-pointing caused a large variation in the Gamma nought Scatterometer data are not available for users	Re-processing of Scatterometer data with the new ESACA algorithm to take into account satellite attitude degradation. Due to the large satellite de-pointing is foreseen that only a small part of the data can be calibrated
ZGM oper	June 7th 2001	Start of Operation with ZGM Satellite de-pointing was reduced within nominal value for the X-Y axis (roll and pitch). De-pointing around Z-axis (yaw) within +/- 2 deg.	Reduction of the gamma nought variation Scatterometer data are not available for users	Re-processing of Scatterometer data with the new ESACA algorithm to take into account satellite attitude degradation. It is foreseen that most of the data can be calibrated User product upgraded with a yaw quality indicator.

Esaca val.	February 4th 2003	Start of the validation Phase for the new Scatterometer processor in Kiruna station It had an impact only for the Gamma nought at the descending passes. Ascending passes were processed with old algorithm at Gatineau station.	The Gamma nought time series (descending) returned around its nominal level Scatterometer data are not available for users	N/a
Regional Mission	July 15th 2003	Failure of the 2 on-board recorders. Data are available only within the visibility of the 4 ESA ground stations (Arctic, Europe, North Atlantic, North-West America) The selected Amazon rain forest is not cover by ESA Low Rate receiving station.	The gamma nought time series is discontinued	Up to now any corrective action is To Be Decided.
Esaca oper	August 21st 2003	During the validation phase the ESACA processor has been upgraded and installed in all the 4 ESA low bit rate receiving station	Scatterometer data re-disseminated to user Only regional mission: Arctic, Europe, North Atlantic, North-West America	

Fig. 4,5 and 6 show the gamma nought time series only for the period for which high quality calibrated data are available. That time series has been corrected by + 0.2 dB from August 1996 to June 1997 and we will refer to it as the "calibrated gamma nought time series". The time series is plotted as function of the parameter Day Of Year (DOY) to highlight the seasonal evolution. Apart some "outliers" (mainly due to a reduced number of samples used in the statistics) the measurements show a good correlation with the DOY.

A qualitative analysis shows that there is 0.1 dB of differences between ascending (night) and descending passes (day) and that the annual variation is around 0.15 dB. No correlation has been found between annual variation in the antenna temperature (see [3] for the antenna temperature evolution) and antenna gain [7].

The reason of that seasonal geophysical signal is questionable: in [8] no correlation has been found between rainfall measured on Benjamin site (Amazon) and gamma nought while in [9] on Guyana rainforest a strong correlation has been found between the accumulative precipitation over a period of about 30 days and the backscattered signal.

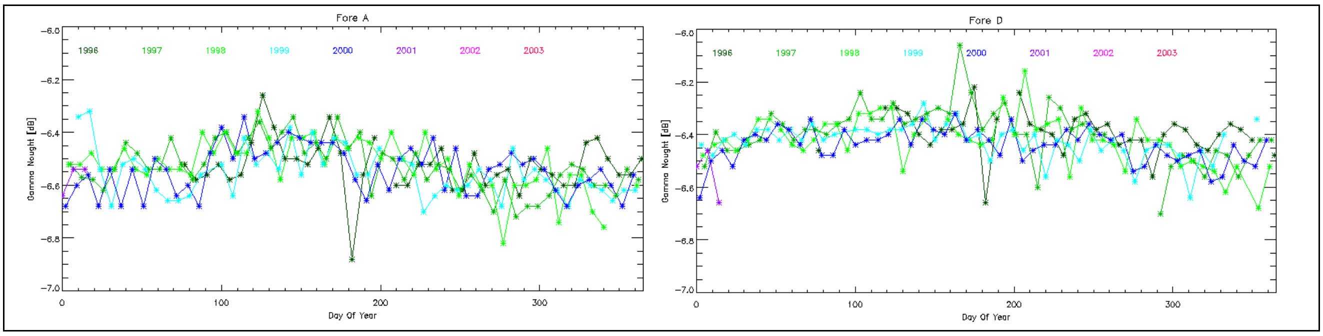


Fig. 4. ERS-2 Scatterometer Calibrated gamma nought yearly time series. Fore antenna (left panel Ascending passes right panel descending passes)

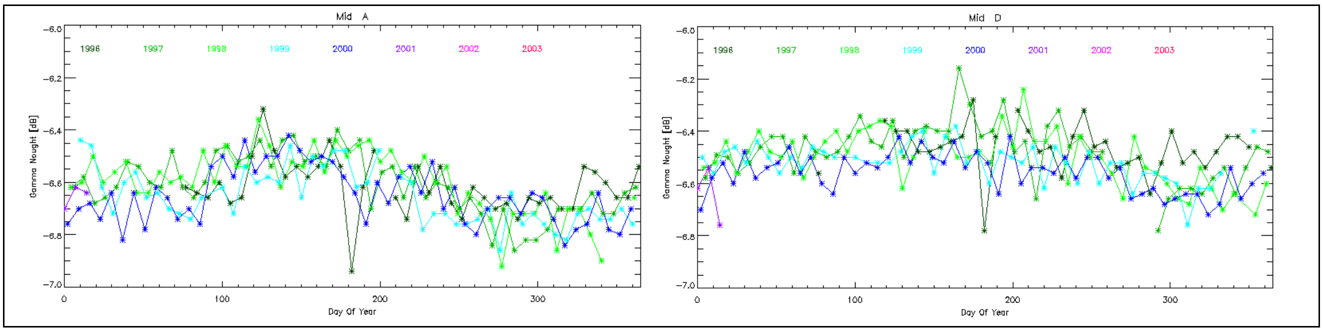


Fig. 5. ERS-2 Scatterometer Calibrated gamma nought yearly time series. Mid antenna (left panel Ascending passes right panel descending passes)

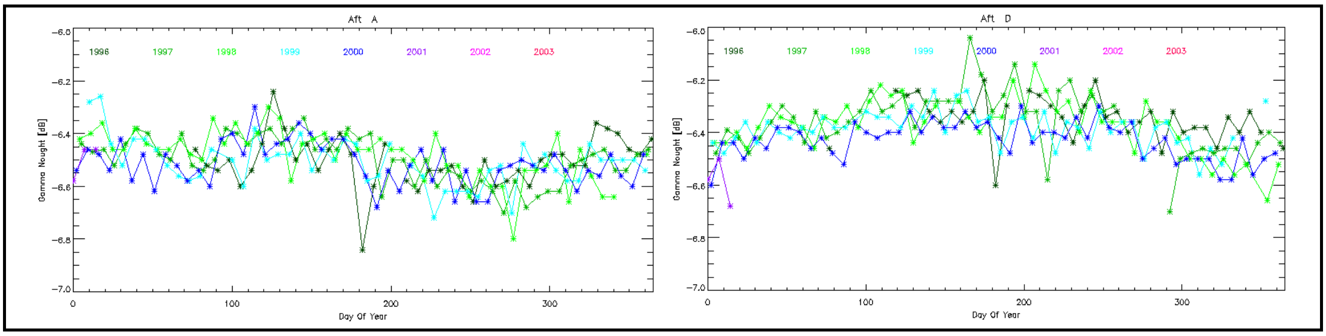


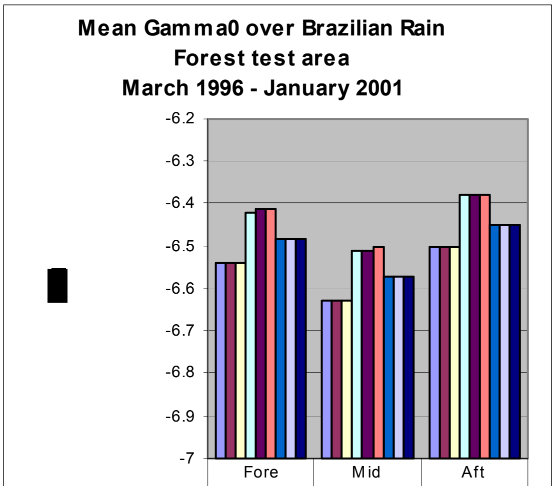
Fig. 6. ERS-2 Scatterometer Calibrated gamma nought yearly time series. Aft antenna (left panel Ascending passes right panel descending passes)

3. Spectral analysis of the calibrated Gamma nought time series

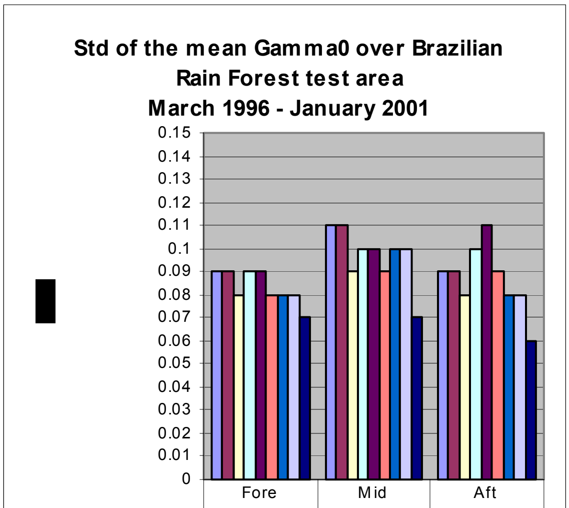
In order to have a better estimation of the Amazon rainforest stability, a spectral analysis of the calibrated time series has been carried out. For each antenna and satellite pass the Fourier Transformer of the calibrated gamma nought time series has been computed. A pre-processing step was needed to assure that all the data gaps in the time series (mainly due to SAR acquisition campaigns over the test area) were filled. This allows us to compute an error-free Fourier Transformer.
As filling strategy an autoregressive model as been used:

$$F(t) = A_1 F(t-1) + A_2 F(t-2) + ... + A_N F(t-N) + W \tag{3}$$

The predicted value F(t) is obtained by a linear combination of the previous N values. The coefficients A are estimated such that they minimize the uncorrelated random error W. With that technique has been filled 8 gaps for the ascending time series and 19 gaps for the descending time series. Due to the limited number of gaps filled (up to 19 on 255 data available) the statistics properties of the times series were not affected. The Fig. 7 shows the mean values (left panel) for the original and gap filled time series, and the same for the standard deviation (right panel).



	Fore	Mid	Aft
Ascending	-6.54	-6.63	-6.5
Ascending filled	-6.54	-6.63	-6.5
Ascending filtered	-6.54	-6.63	-6.5
Descending	-6.42	-6.51	-6.38
Descending filled	-6.41	-6.51	-6.38
Descending filtered	-6.41	-6.5	-6.38
All	-6.48	-6.57	-6.45
All filled	-6.48	-6.57	-6.45
All filtered	-6.48	-6.57	-6.45



	Fore	Mid	Aft
Ascending	0.09	0.11	0.09
Ascending filled	0.09	0.11	0.09
Ascending filtered	0.08	0.09	0.08
Descending	0.09	0.1	0.1
Descending filled	0.09	0.1	0.11
Descending filtered	0.08	0.09	0.09
All	0.08	0.1	0.08
All filled	0.08	0.1	0.08
All filtered	0.07	0.07	0.06

Fig. 7. ERS-2 Scatterometer Calibrated gamma nought time series statistics. Mean Gamma nought (left panel) and gamma nought standard deviation (right panel)

Once the gaps have been removed from the time series we can compute the Fourier transformer of the time series and move the analysis from the time domain to the frequency domain. Fig. 8 shows the Spectrum of the gamma nought series (ascending and descending passes merged).

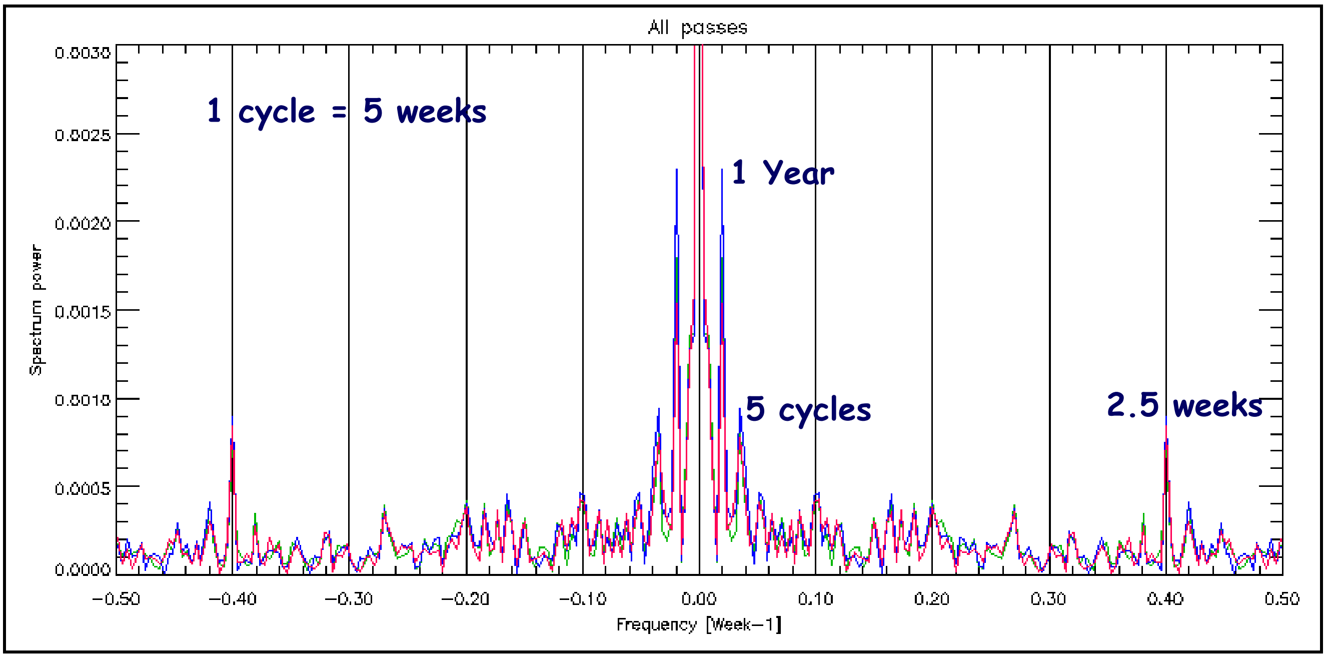


Fig. 8. ERS-2 Scatterometer Gamma nought time series Spectrum. Fore antenna (Red), Mid antenna (Green), Aft antenna (Blu).

In the frequency domain we can discovery some important properties. As expected the spectrum is dominated by a constant term that represents the mean energy from the rainforest. The second term that dominates the spectrum is centered exactly on the frequency of one year. There are also some a-priori not expected signatures centered on 25 weeks and 2.5 weeks. Those peaks are related with the ERS mission scenario and do not correspond to a geophysical signal. In particular the peak around 2.5 weeks is due to the sampling over the test area. As shown in Fig. 9 from [2] the test area is less homogeneous in Longitude than in Latitude. The entire test area can be split into 2 sub areas one in the West the other in the East. The ERS-2 orbit repeat cycle is 35 days or 5 weeks and the presence of slightly inhomogeneous 2 areas modulate the backscattering signal with a 2.5 weekly component. The 25 weeks component corresponds to another sampling effect. In that case the monitoring of the SAR antenna pattern performed every 5 cycles causes a missing data (two ascending and two descending passes) exactly every 25 weeks. Also that fact modulates the time series evolution.

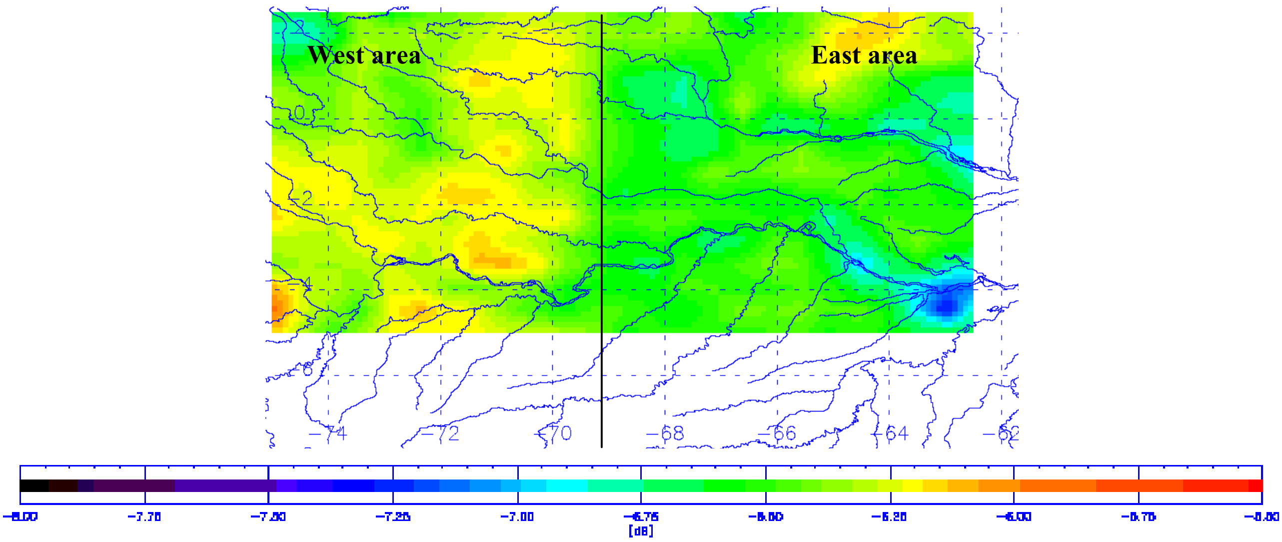


Fig. 9. ERS-2 Scatterometer Fore antenna (ascending) gamma nought image over Amazon rain forest. Cycle 56 August 21st 2000 – September 25th 2000

Those geophysical and sampling effects can be easy removed from the gamma nought time series, by filtering the one year component, the 2.5 and 25 weeks component in the spectrum of the time series. The statistics relative to the filtered time series are reported in Fig 7 (mean) and Fig. 8 (standard deviation). As expected the filtering does not change the mean level of the gamma nought but has improved the performances of the standard deviation. The variability of the gamma nought time series decreases from 0.09 dB to 0.08 dB (Fore/Aft antenna) and from 0.11 dB to 0.09 dB (Mid antenna). More than 10% of the variability of the target can be explained with "geophysical and sampling effects". If we take into account the merged (ascending and descending passes) time series we have a decrease of the standard deviation from 0.08 dB to 0.06 dB (Fore/Aft antenna) and from 0.1 dB to 0.07 dB (Mid antenna) with an improvement up to 30% (Mid beam). Those numbers show that for long-loop monitoring purpose the Amazon rainforest is a stable target within 0.1 dB.

The spectral analysis allows us to characterize the seasonal variation of the Amazon rainforest with the following simple model:

$$\gamma^0_{rainforest}(t) = \sum_{beam=1}^{3} \gamma^0_{beam} + \frac{\sum_{beam=1}^{3} Peak-to-peak_{beam}}{2} \cos(2\pi F_0 t - T_0) \tag{4}$$

The constant component and the one-year component of Eq. 4 are extracted from the Fourier series. The mean level of the signal as well as the amplitude of the variation are obtained by averaging the signal of the 3 Antenna to compensate for the slightly differences in the calibration. The parameters of the model are given in Table 2 and are function of the satellite pass: ascending for the night and descending for the day. The parameter T_0 is mid June, the frequency F_0 is one year.

Table 2 Seasonal variation of the Amazon rainforest as sensed by ERS-2 Scatterometer [dB]

Beam	Ascending		Descending		All	
	Gamma 0	Peak-to-peak	Gamma 0	Peak-to-peak	Gamma 0	Peak-to-peak
Fore	-6.54	0.13	-6.43	0.14	-6.40	0.13
Mid	-6.63	0.20	-6.52	0.15	-6.57	0.17
Aft	-6.50	0.12	-6.39	0.17	-6.45	0.11

4. Conclusion

Up to now 5-years of high quality ERS-2 Scatterometer gamma nought measurements are available over the Amazon rainforest: from Mid March 1996 until beginning of January 2001 when was put in operation the ZGM attitude control system. The new configuration caused a degradation of the ERS-2 Scatterometer data and the interruption of the data dissemination to the end-users. A re-processing of the data acquired in ZGM with the new Scatterometer algorithm (ESACA) will assure a continuous high quality Gamma nought time series from the beginning of ERS-2 mission (April 1995) until June 2003 (end of global mission due to the failure of on-bard recorders). The effectiveness of ESACA has been also proven during the validation phase by comparing the new data with the historic gamma nought time series.

The analysis of the gamma nought time series has been extended to the frequency domain and interesting features has been found. In particular the time series is characterised by some frequency due to the ERS-2 repeat cycle and some inhomogeneous area of the test site. An important spectral component has also been found centred on the frequency of one year. That component has been recognised as due to geophysical effect and a simple model has been defined to describe that yearly variation.

5. Reference

1. RK Hawkins et al. Stability of Amazon Backscatter at C-band: Spaceborne Results from ERS-1/2 and RADARSAT Proceedings CEOS SAR workshop, 26-29 October 1999 CNES http://earth.esa.int/pcs/ers/scatt/articles/
2. R. Crapolicchio et al. "The ERS wind Scatterometer mission: routine monitoring activities and results" proceedings Emerging Scatterometer Application workshop ESTEC Noordwijk The Netherlands 5-7 October 1998 ESA SP-424 http://earth.esa.int/pcs/ers/scatt/articles/
3. PCS team, "ERS-2 wind Scatterometer cyclic report", ESA Technical Document http://earth.esa.int/pcs/ers/scatt/reports/pcs_cyclic/
4. R. Crapolicchio et al. "Impact of satellite degraded attitude on ERS-2 Scatterometer data" http://earth.esa.int/pcs/ers/scatt/articles/
5. X. Neyt et al "Scatterometer ground processing review for Gyro-Less Operations" Proceedings SPIE 2002 Remote sensing of the Ocean and Sea Ice http://earth.esa.int/pcs/ers/scatt/articles/
6. P. Pettiaux et al. "Validation of ERS-2 Scatterometer ground processor upgrade" Proceedings SPIE 2002 Remote sensing of the Ocean and Sea Ice http://earth.esa.int/pcs/ers/scatt/articles/
7. A. Stofflen "Antenna gain variation caused by the sun's irradiation." KNMI technical note presented to the ESA Scatterometer Scientific Advisory Group 1996, 6p
8. P Lecomte et al., "ERS wind Scatterometer commissioning and in-flight calibration" proceedings Emerging Scatterometer Application workshop ESTEC Noordwijk The Netherlands 5-7 October 1998 ESA SP-424 http://earth.esa.int/pcs/ers/scatt/articles/
9. IH Woodhouse, JJ van der Sanden and DH Hoekman, "Scatterometer observations of seasonal backscatter variation over tropical rainforest," *IEEE TGR*S, vol. 37, 1999, pp. 859-861