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Gamma-naught stability assessment of Amazon Rain Forest using C and L band data

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8. Abstract	Amazon Rainforest is widely used as distributed target site for Synthetic Aperture Radar (SAR) calibration. Although it is a natural dense rainforest, deforestation and fires are reducing the current forest coverage, and also widespread tree mortality. The response of this site in radar data shows a remarkably high degree of homogeneity over a large area, but still it has some spatial and temporal variability due to deforestation effects and seasonal variability which impacts the SAR calibration accuracy. Hence in this study, temporal and seasonal variation of backscatter of this rainforest have been analyzed using available SAR data of Sentinel -1A, 1B and ALOS-2 PALSAR mosaic data. Data acquired over the southwest Amazon during three years (2015-2017), including wet and dry seasons has been used for the analysis in this study. Subset of the data was taken which contains the common area for both the bands. After that, calibration and generation of backscattering coefficient image (σo) was done. In order to avoid the water pixels, water mask was generated using the backscattering values derived from the

	image itself. The mean value of γo for co-polarized data of Amazon Rainforest for the study period was found to be -6.5 ± 0.78 dB and -6.5 ±0.27 dB for C and L band respectively. For cross-polarized data, the values were found to be -12.5±0.86 dB and -12.5 ±1.83 dB for C and L-band respectively. Seasonal variation of 0.04 dB in co-pol and 0.07 dB in cross-pol for C-band is estimated. As seasonal variation is insignificant, it can be considered that Amazon rainforest has been stable during the study period.
9. Key words	Time series Gamma Naught, Sentinel-1, ALOS-2, Amazon rain forest, distributed target, SAR calibration.
10. Security classification	Unrestricted
11. Distribution statement	General

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1. Introduction

The most important plant communities of the Amazon rainforest are algae, aquatic and semi-aquatic herbaceous plants and forest. These communities have adapted to survive in an environment that change by season, year, decade and century, because of the flood pulse of the Amazon. The determination of the gamma naught stability without atmospheric interference at the Amazon scale is only possible using remotely sensed data. Optical satellites are limited because of intense cloud cover over the Amazon region. For instance, Novo et al. had to acquire 10 years of LANDSAT data to produce a cloud-free mosaic of part of the Amazon rainforest. Therefore, Synthetic Aperture Radar (SAR) satellites are currently the most suitable systems to study the Amazon rainforest because of their all-weather functionality and their independence from the Sun as an illuminationsource. (Costa, 2004)Moreover, microwave radiation interacts differently with each object present in the area. The characteristics of the plant (density, distribution, orientation, shape of the foliage, dielectric constant, height and branches), the ground (dry, moist and flooded) and the sensor (polarization, incidence angle and wavelength) are important in determining the radiation backscattered towards the radar antenna.

Amazon Rainforest is widely used as distributed target site for Synthetic Aperture Radar (SAR) calibration. Although it is a natural dense rainforest, deforestation and fires are reducing the current forest coverage, and also widespread tree mortality. The response of this site in radar data shows a remarkably high degree of homogeneity over a large area, but still it has some spatial and temporal variability due to deforestation effects and seasonal variability which impacts the SAR calibration accuracy. Hence in this study, temporal and seasonal variation of backscatter of this rainforest have been analyzed using available SAR data of Sentinel -1A, 1B and ALOS-2 PALSAR. Data acquired over the southwest Amazon during three years (2015-2017), including wet and dry seasons has been used for the analysis in this study.

Previously work has been conducted for Amazon rainforest to determine its stability/consistency in gamma naught values using satellite data and various ground observation techniques. The previous research work were conducted for the year 1890's to 2000. In this paper, gamma naught values are calculated for the present scenario i.e., year 2015 to 2017, which helps in determining the suitability of Amazon rainforest, which is a uniformly distributed target- as relative calibration site for future SAR calibration activities. Consistency in gamma naught values is one of the key parameter in deciding the suitability of the calibration site. It is achieved by calculating gamma naught values for intra annual (seasonal) and inter annual of the year 2015 to 2017.

The introduction of the Amazon rainforest, objectives, study area and description of the data used for the analysis are briefed in section 2, 3 and 4 respectively. The methodology adopted to obtain the gamma naught values of the forest is explained in section 5. Section 6 describes the inferences made from intra annual, inter annual and quantitative comparison of gamma naught values obtained using C and L band data. Section 7 summarizes the conclusions of the study.

2. Objectives

The major objective of the study is to assess the intra-annual and inter-annual gamma naught variations of the Amazon Rainforest, using C and L band data of the Sentinel-1 and PALSAR-2 satellites respectively for the years 2015, 2016 and 2017.

3. Study Area

Amazon Rainforest is a moist broadleaf forest in the Amazon biome that covers most of the Amazon basin of South America. It is geographically located at **3.4653° S, 62.2159° W.** This basin encompasses 7,000,000 km^2 (2,700,000 sq. mi), of which 5,500,000 km^2 (2,100,000 sq. mi) are covered by the rainforest. This region includes territory belonging to nine nations. The majority of the forest is contained within Brazil, with 60% of the rainforest, followed by Peru with 13%, Colombia with 10% and with minor amounts in Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guiana. The Amazon represents over half of the planet's remaining rainforests and comprises the largest and most bio diverse tract of tropical rainforest in the world, with an estimated 390 billion individual trees divided into 16,000 species. Biomass ranges from 100 to 300 tons/ha with annual precipitation, approximately 3 m. This region is the source of ~30% of the oxygen flux, a storehouse of biodiversity and a natural indicator of climate and other ecological changes. Amazon rainforest is used to determine stability for intra annual and inter annual because it is spread across several square miles in azimuth and range direction with respect to onboard satellite sensor and satisfying the requirements of an ideal calibration site.

Fig1. States of Amazonas - Amazon Rain Forest

4. Data Used

4.1 Sentinel-1

Sentinel-1 is equipped with a SAR sensor operating at C-band (5.405 GHz). The data acquired is level -1 GRD (Ground Range Detected). This product consists of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Ground range coordinates are the slant range coordinates projected onto ellipsoid of the Earth. Pixel values represent detected magnitude. Phase information is lost. (Hub, n.d.)

GRD products available in three resolutions, characterized by the acquisition mode and the level of multi looking applied.

- Full Resolution, High Resolution, Medium Resolution.

Product resolutions by mode:

- Strip Map GRD, Interferometric Wide Swath GRD, Extra Wide Swath GRD.

Table 1. Details of Sentinel-1 data

Satellite:	**Sentinel-1**
Product Type:	Ground Resolution Data
Sensor mode:	Interferometric Wide swath
Acquisition mode:	Dual Polarization
Radar Center Frequency (GHz):	5.404999
Radar Wavelength(m):	0.055466
Study Year:	2015, 2016,2017
Spatial Resolution	10 m * 10 m

4.2 PALSAR 2:

PALSAR 2 (Phased Array Type L Band Synthetic Aperture Radar) is equipped with a SAR sensor operating at L-band (1.2 GHz) with a Dual Polari-metric mode. The data obtained from Advanced Land Observing Satellite 2 (ALOS 2). PALSAR 2 mosaic is a seamless global SAR image created by mosaicking the SAR images in backscattering coefficients. The strip data with 10*10 degree in latitude and longitude are path processed and mosaicked for processing efficiency. PALSAR-2 Forest & Non-Forest mosaic product is generated by classifying the backscattering intensity values, so that strong and low backscatter in HV polarization are called 'forest' (colored in green) and 'non-forest' (colored in yellow) respectively. The classification accuracy is more than 84% when compared with in-situ photos and high-resolution optical images. (shimda, 2007) The mosaic product has spatial resolution of 25 m and global mosaic data with temporal interval of one year.

Table 2 Details of PALSAR 2 data

Satellite:	**ALOS 2**
Product Type:	HDR
Sensor mode:	PALSAR 2
Acquisition mode:	Dual Polarization
Radar Center Frequency (GHz):	1.2
Study Year:	2015, 2016, 2017
Spatial Resolution	25m * 25m

5. Methodology

Stability evaluation of the gamma naught values for Amazon Rain Forest: - Rain forest is a uniform, distributed and reference target for relative (range and azimuth antenna pattern determination) and absolute calibration target. Reflectivity estimates (sigma or gamma naught) are calculated which helps to understand the stability of the Amazon rainforest. To calculate gamma naught values, the formula used was:

$$\boldsymbol{\sigma^\circ = 10\ \log_{10}\langle DN^2\rangle + CF}$$

DN = digital number of the intensity image.

CF = calibration factor, -83.0 dB

The following procedure is used to calculate gamma naught values for both C and L band data:

Common area shared by both C and L band data was selected. The coordinates for the study area are **$49^0$58’34’’ N, $84^0$00’00’’ W; $50^0$59’54’’ N, $84^0$59’57’’ W.** Pre-processing of data is required to apply gamma naught formula. Calibration is the important step providing the pixel values that are directly related to the radar backscatter of the scene. Though un-calibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential for quantitative use of SAR data.

For performing the calibration step, following equation is used:

$$\text{Value (i)} = \frac{DN^2}{Ai^2}$$

where, value (i) = original DN

Ai = dn(i), Gamma Naught

The steps used in the analysis are shown in Figure 2.

For masking out the water pixels, two methods can be utilized which are shown below:

- Based on the intensity values: In this, histogram is generated for the intensity image and from the histogram, minimum value was used to select water pixels. Either sigma naught or gamma naught may be used to select water pixel. The condition applied is "*IF Sigma_VV<1.25E-2 then 1 else 0*". This condition selects the water pixels.
- Based on sample water pixels' histogram: In this, samples of water pixels are selected and histogram is generated. The threshold values observed were Pixels, which lie between -12 dB to -27 dB, selects all the water pixels. These values are used to remove the water pixels from the image.

In this study, water pixels were masked out by using histogram method.

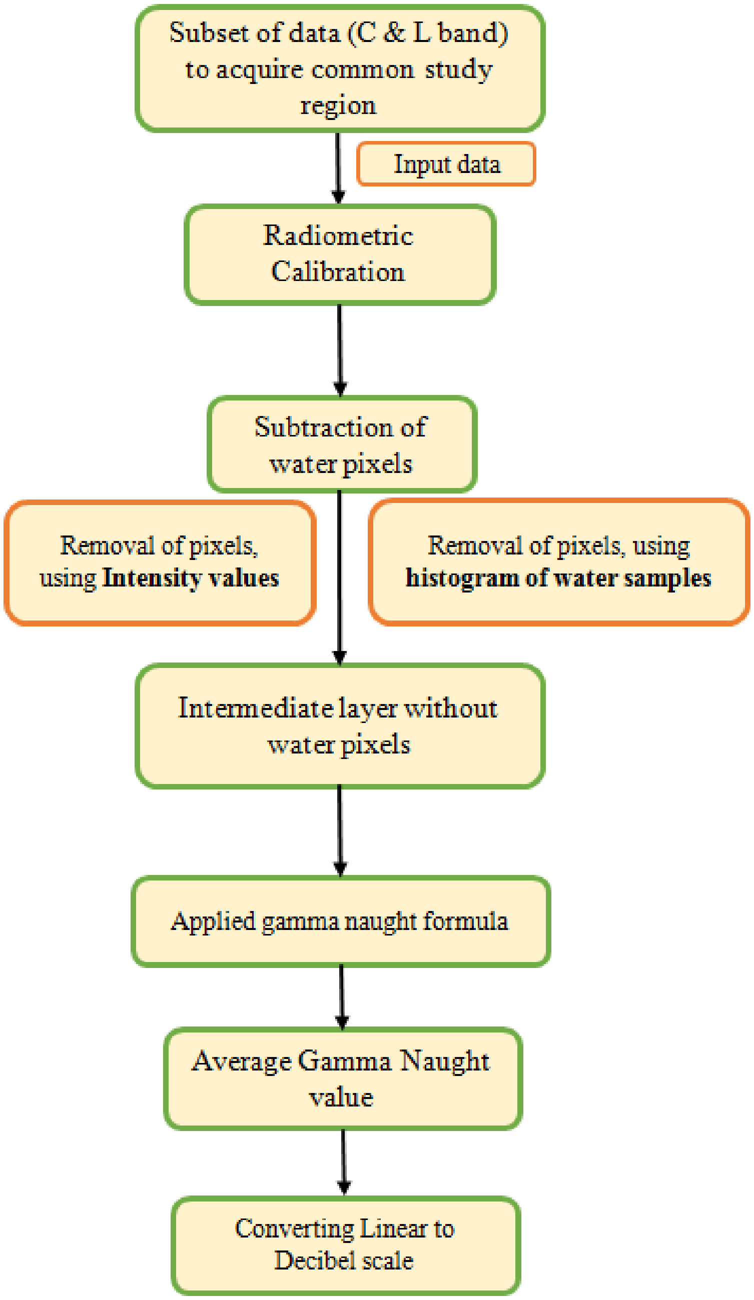


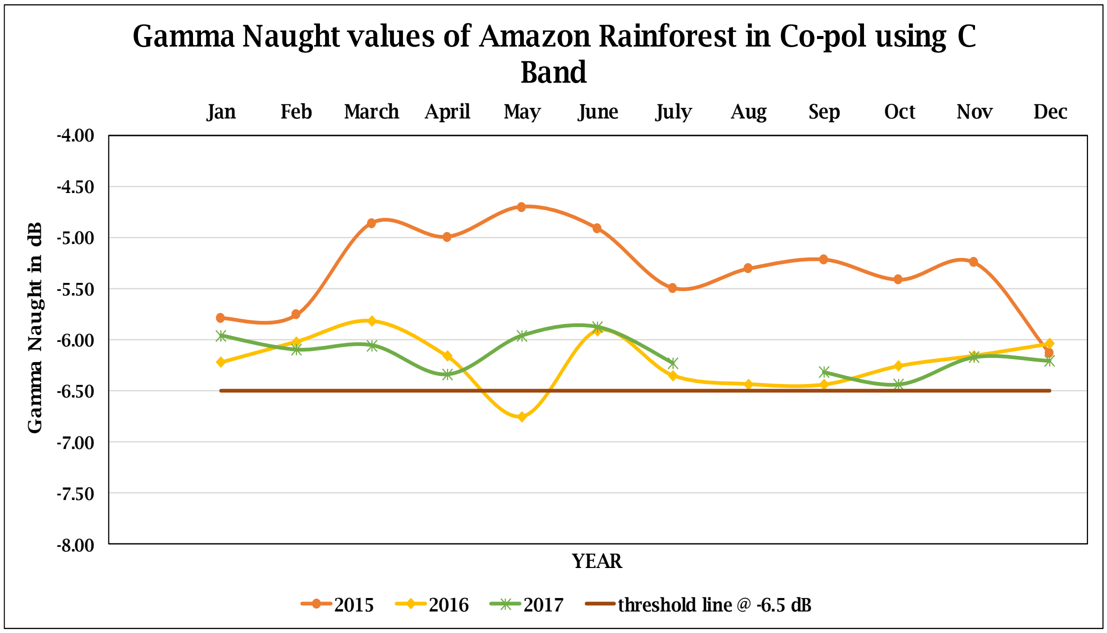
Fig.2 Flow-chart showing methodology

The intermediate layer contains only forest pixels i.e., without water, which is used to calculate gamma naught values. The calculated gamma naught values are in linear scale which is converted to decibel scale for further observations.

6. Results & Discussion

After Gamma Naught calculations for common region over Amazon Rainforest, the following observations are noted.

6.1Variation of gamma naught values – inter annually: Using C band



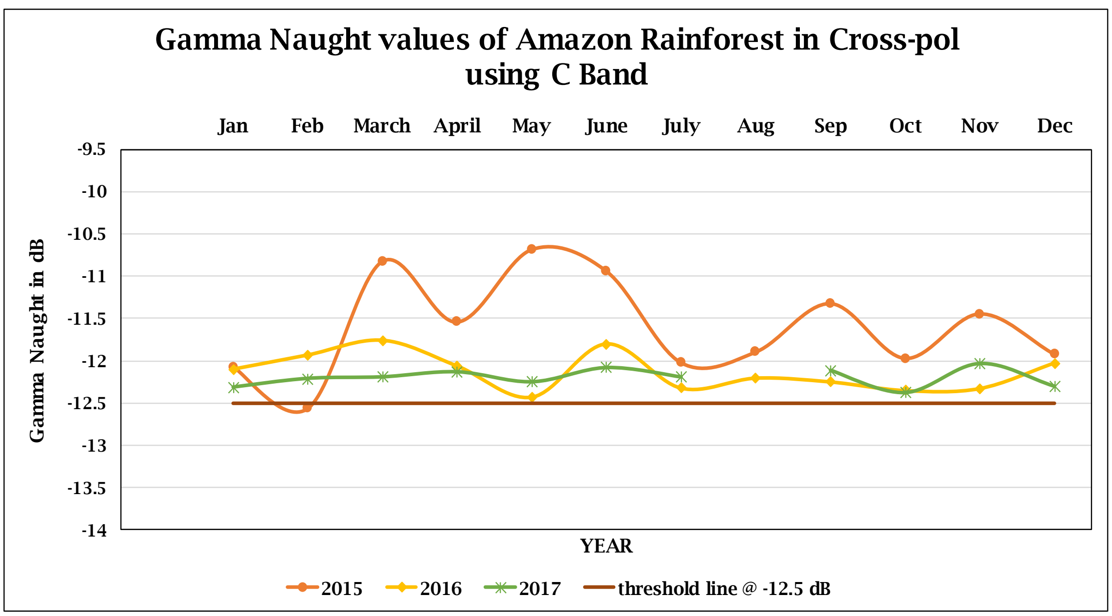


Fig.3 Inter-annual Gamma Naught values of Amazon in Co & Cross-pol using C band

The above year wise inter annual graph of Amazon rainforest displays the gamma naught values calculated for years 2015, 2016 &2017 respectively using C band data from Sentinel-1 satellite. The time series graph helps to understand the changes in gamma naught values, which occurred in the observation period and to observe the stability of rainforest in different polarization of the data. Amazon Rainforest has Rainy and dry seasons, rainy season starts from October to May and Dry / summer season is from June to September. In Rainy season, heavy rainfall occurs up to 80to 430 inches*(rainforest.mongabay, n.d.)*, which leads to ice formation, hailstorm and presence of moisture on leaves, which give low backscatter. In dry season, healthy vegetation is present within significant amount of moisture content on leaves, receiving high backscatter from rainforest.

From the above graph- the 2015-year data-line, shows that the gamma naught values of co-pol (HH, VV) in the rainy season (March, April, May and June) are near to -4.70 dB, and in the dry season i.e., from July to November, the gamma values are consistent and near to -5.5dB. The gamma naught values in rainy season are effected due to presence of ice content, soil moisture and various kinds of vegetation (shrubs, canvas), which gives low backscatter values and in the dry season, backscatter is purely from canopy of the tree due to healthy vegetation. Throughout the year, the gamma naught values in co-pol (HH, VV) vary from -5.79 dB to -6.04 dB and can also represent as -6.5± 0.71 ~ 0.37 dB respectively. While in cross-pol (HV, VH), the values vary from -12.07 dB to -11.92 dB, the gamma naught value can also be -12.5±0.43 ~ 0.58 dB

From the above graph- 2016-year data-line, the gamma naught values observed to be mostly consistent, with minor disturbance in May. The disturbance may be due to presence of ice content, hailstorm and it could be possibly due to change in polarization of data. We observed that the data before month of May and after June has HH polarized data and June data is in VV polarization. Throughout the year, the calculated gamma naught values in co-pol (HH, VV) vary from -6.22 to -6.04 dB i.e., within -6.5 ± 0.28 ~ 0.46 dB. The gamma value in cross pol (HV, VH), observed to be varying from -12.09 to 12.03 dB i.e., within -12.5 ± 0.41 ~ 0.47 dB

From the above graph- 2017-year data-line, the gamma naught values observed are even and consistent, without any noticeable variation in calculated gamma values. Throughout the year, the calculated gamma naught values in co-pol (HH, VV) vary from -5.96 to -6.21dB i.e., within -6.5 ± 0.54 ~ 0.29 dB The gamma value in cross pol (HV, VH), observed to be varying from -12.3 to -12.45 dB i.e., within -12.5 ± 0.19~ 0.46dB

Even with the presence of sudden rise and fall of the gamma naught values, it is observed that the graphs patterns are similar and proximately overlapping each other.

From the above inter annual graphs and discussions, the calculated average gamma naught valueis-**6.5 ±0.78dB**in co-pol (HH, VV) and **-12.5 ± 0.86dB** in cross-pol (HV, VH).Consistent stability is observed over the study area of Amazon Rainforest. Meanwhile, understanding the aftermath on gamma values due to season change is the key factor deciding the stability of the rainforest.

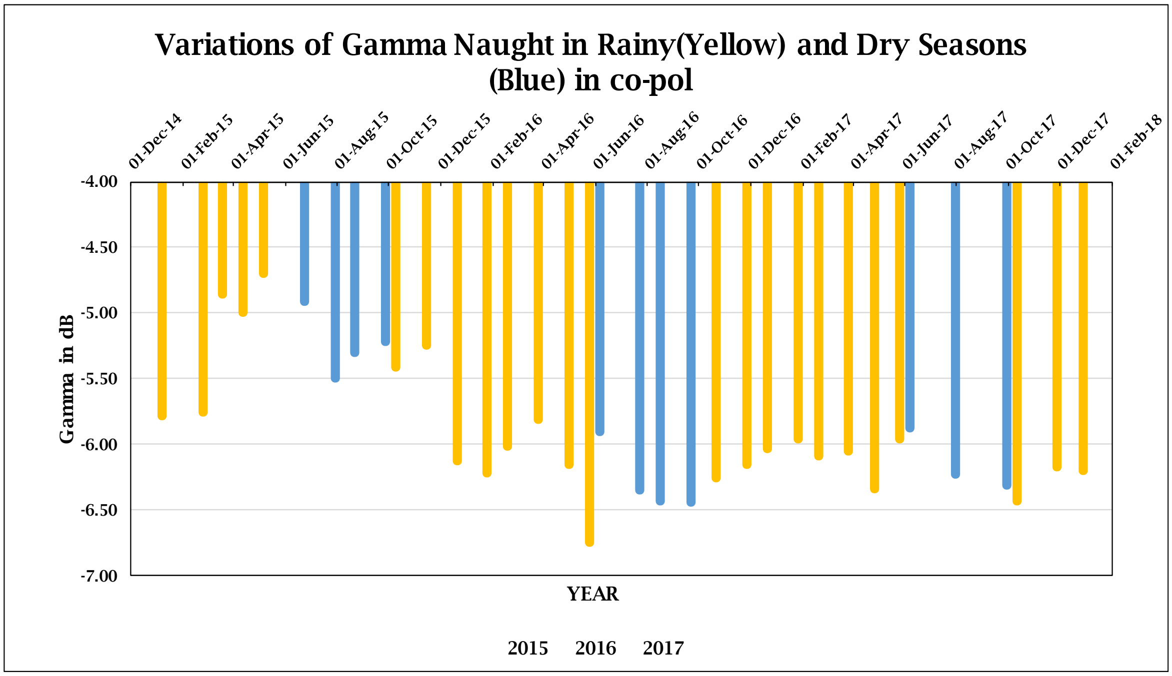
6.2 Variation of gamma naught values in Rainy and Dry season-intra annually: Using C band

As season change, backscatter from the target varies which cause changes in gamma naught calculations. Understanding these variations in gamma naught values due to change in seasons of the Amazon rainforest is important as it decides the stability throughout the year of the distributed target site. Amazon rainforest is more prone to rainy season rather than other seasons. The Amazon rainforest has *Rainy*Season-October to May and *Dry* Season-June to September. Accordingly, data is separated and plotted for rainy and dry seasons, which is distinguished by yellow and blue colors respectively.

In Amazon forest the gamma naught values in co-pol (HH, VV), are varying from -5 dB to -6.34 dB in rainy season and -4.91 dB to -6.44 dB in dry season respectively. If we observe the above graph, the years (2015, 2016, and 2017) considered has -5.5 dB as constant gamma-naught value in both rainy and dry seasons. The gamma naught value in co-pol can be written as**-6.5 ± 0.60 dB in rainy season** and**-6.5 ± 0.64 dB in dry season.**

In cross-pol, the gamma naught value varies within -12.07 dB to -12.31 dB in rainy season and -10.94 dB to -12.11 dBin dry season respectively. From the graph, a constant -11.5 dB is the observed gamma value in rainy and dry season. It can be represented has **-12.5 ± 0.51 dB in rainy season and -12.5 ± 0.58dB in dry season.**

Between rainy and dry season,seasonal variation observed was**0.04 dB in co-pol** (HH, VV) and **0.07 dB in cross-pol** (HV, VH). The above difference due to season change is minimal, thus proved that gamma naught value is stable throughout the year independent of season change.



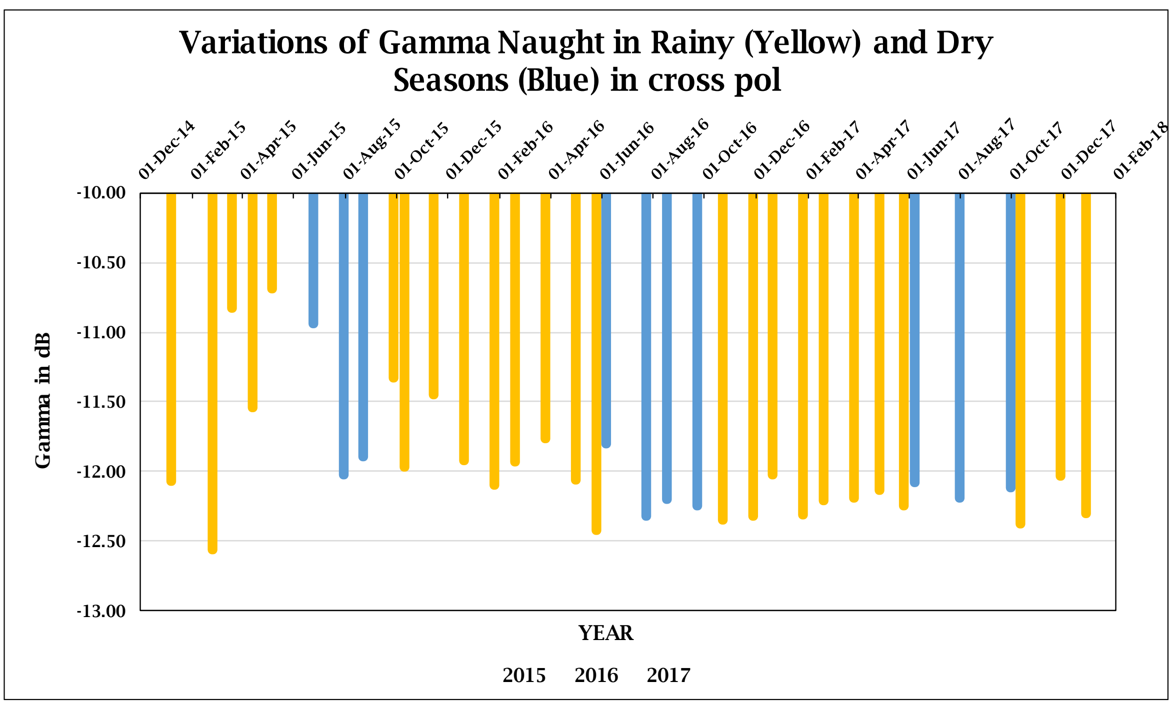
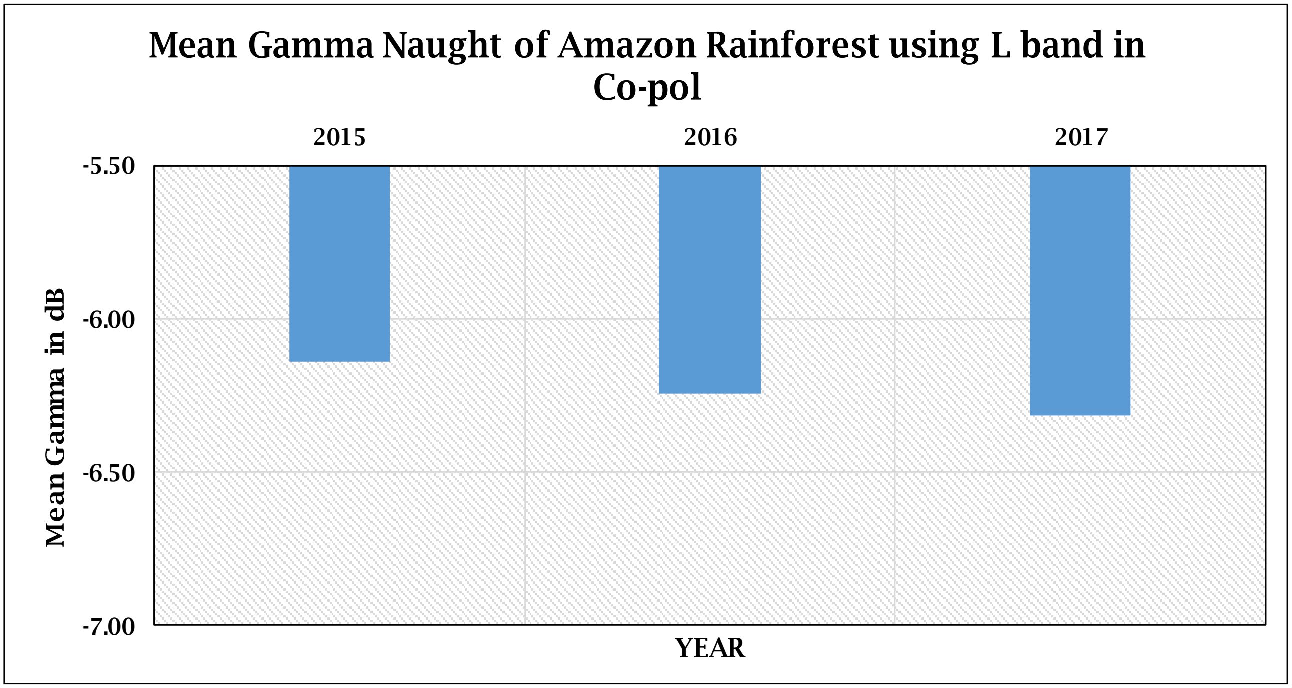


Fig. 4Intra-annual gamma naught values of rainy and dry seasons in co & cross-pol using C band

6.3 Variation of gamma naught values – inter annually: Using L band ALOS PALSAR 2 mosaic data.



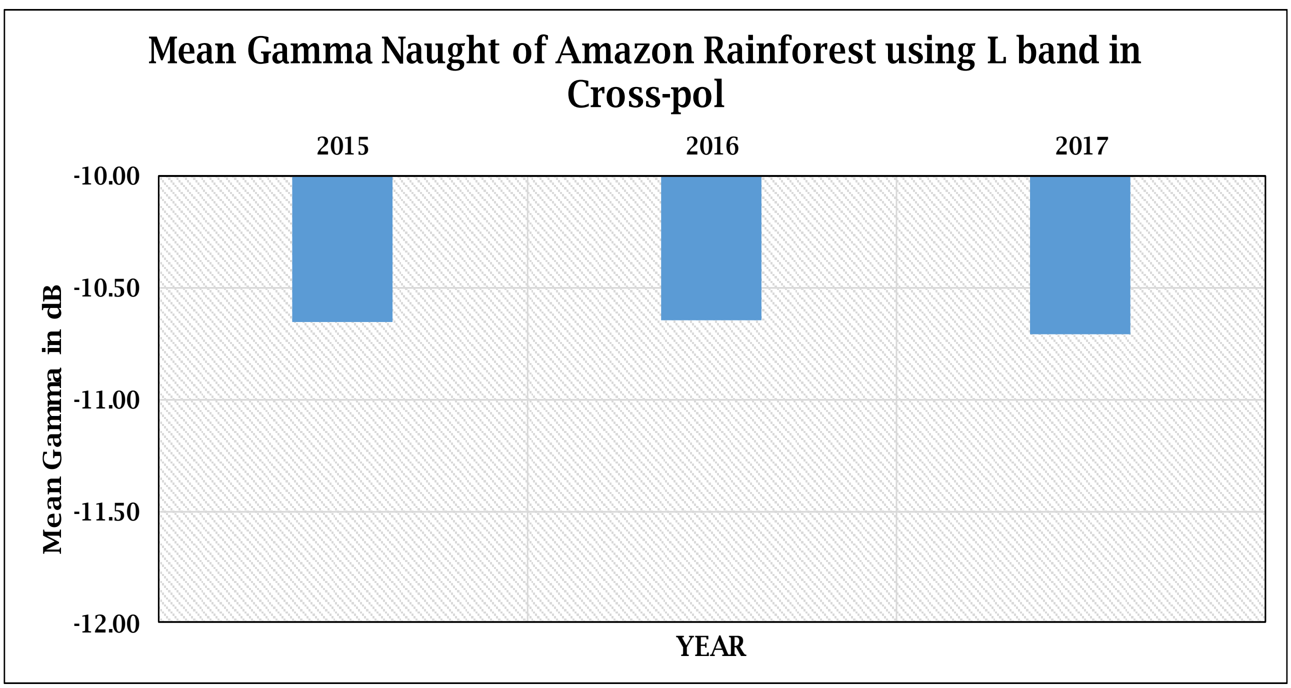
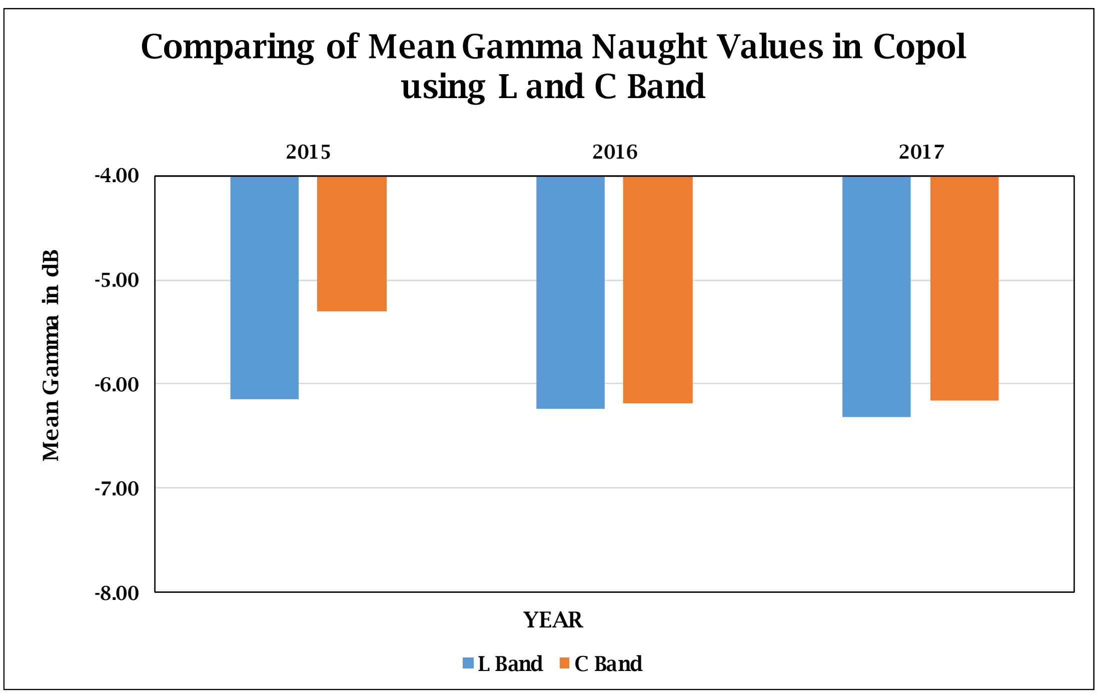


Fig. 5Inter-annual Mean Gamma Naught values of Amazon in co & cross-pol using L band

Gamma naught values of Amazon rainforest are calculated for the years 2015, 2016 and 2017 using L-band mosaic product of ALOS-2.The graph helps in observing that, the gamma naught values are -6.13 dB, -6.24 dB and -6.31 dB in co-pol (HH, VV) and-10.65 dB, -10.65dB and -10.71 dB in cross-pol (HV, VH) respectively. The gamma values with respect to the above mentioned values, fluctuates within -0.36 to -0.19 dB in co-pol and -1.84 dB to -1.79 dB in cross-pol. The gamma naught values are**-6.5 ±0.27dB** in co-pol and **-12.5 ±1.83 dB** in cross-pol. The observed gamma naught values in L band is nearly the same as C band value.

All the section above helps in understanding the stability pattern of Amazon rainforest during the seasonal change and throughout the year, while the section 5.4, helps in quantitative comparison of the L and C band calculated gamma naught values to determine suitable frequency data.

6.4 Inter Annual Comparison of the Mean Gamma Naught values obtained from the data of Sentinel-1 and ALOS PALSAR 2.



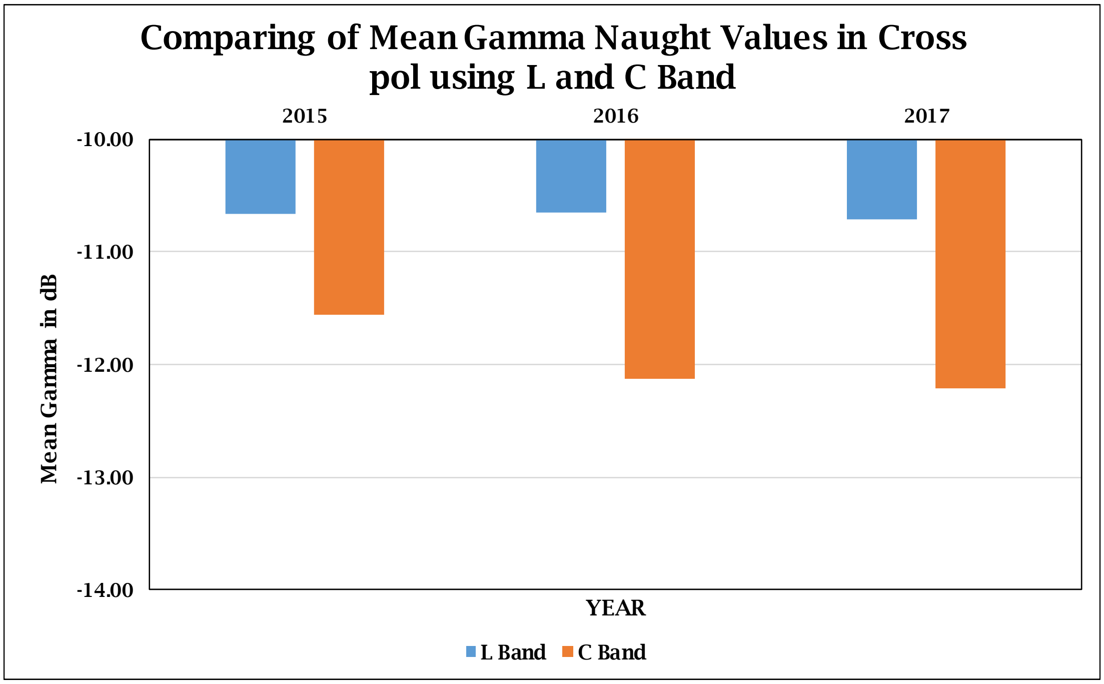


Fig. 6Inter-annual Quantitative Comparison of L and C band's Mean Gamma Naught values in Co & Cross-pol

This Section shows the quantitative difference between L and C band calculated gamma naught values, which helps in determining suitable frequency data to conduct this kind of stability studies for distributed targets. Average mean gamma naught values of L and C band are used to construct the above graph.

In co-pol (HH, VV) the gamma naught values of L and C band are -6.14 dB and -5.30 dB in year 2015, -6.24 dB & -6.19 dB in year 2016 and -6.31 dB & -6.15dB in year 2017 respectively.

Likewise, in cross-pol (HV, VH), the gamma naught values of L and C band are -10.65 dB& -11.56 dB in year 2015, -10.65 dB& -12.13dB in year 2016 and -10.71 dB & -12.21 dB in year 2017 respectively.

From the above values, the average gamma naught value of co-pol and cross-polcan be rewritten as **-6.5 ± 0.27 dB &12.5 ± 1.83 dB** of **L band and -6.5 ± 0.78 dB & -12.5 ± 0.86dB**of **C band** respectively.

From the above values, it is interpreted that the gamma naught values of Amazon rainforest are nearly ideal in both L and C band results with minor differences. It also confirms that it is stable and best suitable for calibration activities of SAR sensors. Another conclusion can also be made that C band is more suitable for stability analysis as C band waves strike the scatter on the surface and return as backscatter purely from canopy, while in L band more backscatter is received as it strikes the branches, twigs, leaves of the tree, which is surplus information for this study. We can conclude that in absence of L band near real time data, C band would be other best alternative.

Inter-annual gamma naught values of C and L band data are shown in Figure 6. The gamma naught value of C band, data are -5.30 dB, -6.19 dB and -6.15 dB in co-pol and -11.56 dB, -12.13 dB and -12.21 dB in cross-pol for 2015, 2016 and - 2017 respectively.

Comparison with the results reported in the literature

1. Prototyping Radio-metrically Terrain Corrected Sentinel-1 Data at the Alaska Satellite Facility(Hogenson):

The results show that the RCS for the co-pol product was near or at the accepted value of -6.5 dB in Gamma naught over the Amazon rainforest. The average cross-pol RCS was around -12.5 for these same products. Both processors preserved the calibration quality of the original GRD products provided by ESA.

2. PALSAR radiometric and geometric calibration(Isoguchi, 2010):

Amazon forest provides a constant and almost seasonally independent gamma-naught for a wide range of incidence angles and can be used as a reference calibration target.
JERS-1SAR confirmed that the NRCS-NORMALIZED RADAR CROSS SECTION of the Amazon forest is seasonally independent with a value of -7.5 dB and a **seasonal variation of 0.27 dB** thus, the corresponding gamma-naught is -6.5 dB. PALSAR data has strip mode, average gamma naught of -6.52 dB with standard deviation of 0.22dB for all incidence angles.SCANSAR has -6.65dB with deviation of 0.4dB

3. Long-term stability of L-band normalized radar cross section of Amazon rainforest using the JERS-1 SAR: (Shimda M. , 2005)

This paper describes the long-term stability of L-band synthetic aperture radar (SAR) data observed over the Amazon and the applicability of the Amazon as a calibration reference. The author evaluated 139 Japanese Earth Resources Satellite 1 (JERS-1) SAR images acquired over the southwest Amazon during six and a half years (1992–1998), including wet and dry seasons. During each season, the data appeared to be stable, with mean values of –6.81 and –7.08 dB, standard deviations of 0.20 and 0.18 dB, and a 0.27 dB difference between the two seasons. The Amazon is thus a stable reference for calibration.

4. PALSAR CALVAL Summary: *(shimda, 2007)*

The statistical analysis shows that the **seasonal variation is only 0.25 dB, which shows the stabililty of** Amazon rainforest. The limited condition for the deployment of the corner reflector requires the inclusion of the Amazon based calibration both for relative and absolute calibration. At the beginning of the PALSAR Cal-Val, they determined the gain offset among the beams, which is so that the gamma naught could be constant over the incidence angle, i.e., $\gamma^\circ = \frac{\sigma^\circ}{cos\theta}$= constant. Where, θ is the incidence angle. They confirmed the validity of this assumption using the 10 Amazon data for the strip mode and two data for the SCANSAR.

7. Summary and Conclusions

This study aims at assessing the stability of the gamma naught for Amazon rainforest during the time period 2015-2017. Intra-annual and inter-annual comparisons of gamma naught values were done and results are reported here for both C- and L-band using available SAR data of Sentinel -1A, 1B and ALOS-2 PALSAR mosaic data..

Using C-band data, average gamma naught value is estimated as -6.5 ± 0.78 dB in co-pol (HH, VV) and -12.5 ± 0.86 dB in cross-pol (HV, VH) respectively. The average gamma naught valuesfor rainy season are -6.5 ± 0.60 dB &-12.5 ± 0.51 dB and -6.5 ± 0.64 dB &-12.5 ± 0.58 dB in dry season for co-polarisation and cross-polarization data respectively. Seasonal variation of 0.04 dB in co-pol (HH, VV) and 0.07 dB in cross-pol was observed. The seasonal variation in gamma naught value is found to be minimal for Amazon rainforest for C-band data.

Using L band mosaic product, average gamma naught values estimated are -6.5 ±0.27 dB in co-pol &-12.5 ±1.83 dB in cross-pol respectively. Due to non-availability of day wise data, Seasonal analysis were not performed. The second objective of the study is the quantitative comparison of the C and L band results. The mean gamma values of C and L band are -6.5 ± 0.78 dB & -12.5 ± 0.86dB and -6.5 ± 0.27 dB &-12.5 ± 1.83 dB respectively. The gamma values obtained using C band data are true and significant because near to real time data is available, while in L band the data used was the mosaic product of real time data and in-depth studies cannot be performed.

From this analysis, it can be concluded that Amazon rainforest is stable during the study period 2015 - 2017 and can be continued to be used as a calibration site for SAR data.

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