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Precipitation Effects for X- and Ka-band SAR

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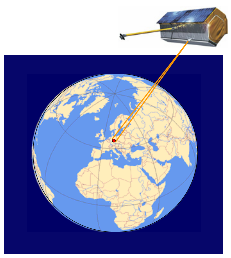
Abstract

Space-borne Synthetic Aperture Radar (SAR) imaging is often considered to possess both day/night and all weather operational capabilities. Whereas the first argument is true since we are dealing with an active sensor; the second does not hold in cases for which the operating frequencies are above 3 GHz. Indeed, the SAR performance can be significantly affected by atmospheric effects (losses), especially at unfavourable weather conditions. The principal reasons for the restriction on the use of these higher frequencies can be found in clear air losses (water vapour and oxygen), cloud attenuation and attenuation due to precipitation, primarily rain.



- **Gaseous component** (oxygen and water vapour)
  -> always present
  - increases with increasing frequency
  - dependent on temperature, pressure, and humidity
- **Hydrometeors** (rain, snow, hail etc.)
  -> certain period of time
  - ***Rain:*** (I) can produce major impairments depending on climatic region. (II) probability for precipitation in Greenland as well as Antarctica is very low
  - ***Dry snow and ice particles:*** usually so low that it is unobservable for frequencies below 50 GHz.
- ***Clouds and fog:*** much less severe than rain, however present much larger percentage of time than rain

- Note: The lower the elevation angles the more attenuation becomes significant

1. Typical rain induced signatures in SAR images

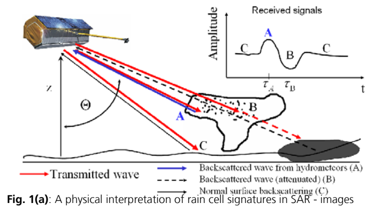


Fig. 1(a): A physical interpretation of rain cell signatures in SAR - images

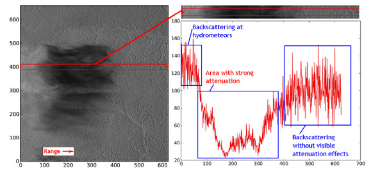


Fig. 1(b): A physical interpretation of rain cell signatures in SAR - images

- The dark patches in Fig. 1(b) are due to the attenuation of the transmitted signal through the precipitation medium (shown as volume "B" in Fig. 1(a)).
- The white shading in Fig. 1(b) is due to direct reflections from the rain region (hydrometeors, like larger raindrops and hail) and is shown as volume "A" in Fig. 1(a).

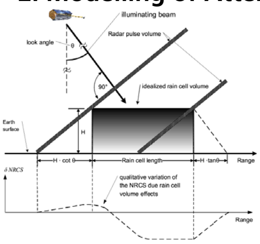
Backscattering due to precip.

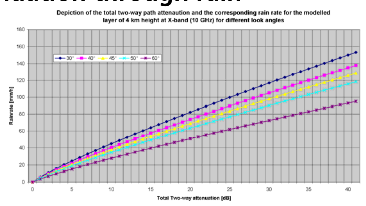
$$\sigma_b = \frac{\pi^5}{\lambda^4}|K|^2\sum_{i=1}^{N} \cdot D_i^6$$

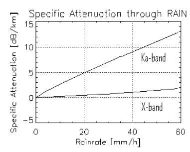
$$\hat{Z} = \int N(D_e)D_e^6 dD_e \qquad [\mathrm{mm}^6/\mathrm{m}^3]$$

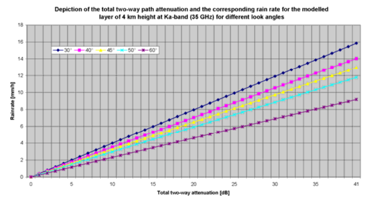
$$\hat{Z} = a_1 \cdot R^{b_1}$$

2. Modelling of Attenuation through rain









$$\gamma(x,t) = a \cdot R^b \qquad \gamma(t) = \frac{A(t)}{2 \cdot \frac{H}{\cos(\theta)}} \qquad [\mathrm{dB/km}]$$

$$A(t) = \int_0^{2h} \gamma(x,t)dx \qquad R = \sqrt[b]{\frac{\gamma(t)}{a}}$$

$A(t)$ ... total attenuation for given time instant t
t ... time
h ... path length
$\gamma(x,t)$ ... specific attenuation
x ... position along the path of propagation

3.

Atmospheric Losses for Polar-, Europe-, and Tropical Regions for X- (9,6 GHz) and Ka-band (35 GHz)

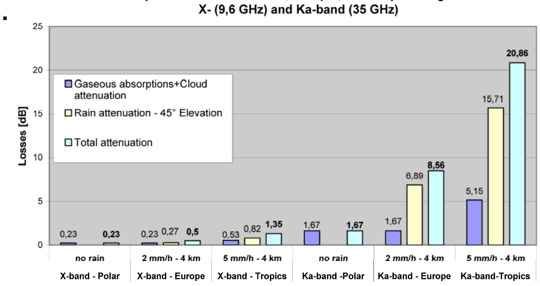


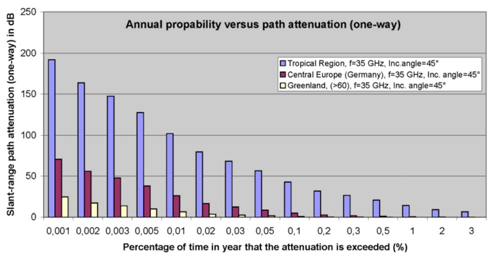
Figure: The diagram shows the main contributions to the atmospheric budget. Beside Ka-band, X-band is considered for the sake of comparison. The analysed regions are Polar-, European- (for alpine glacier monitoring) and tropical regions. Polar regions exhibit similar values compared to Alpine glaciological regions in Europe in terms of gaseous and cloud attenuation however excluding rain attenuation. Please note that for the reason of clarity the contributions due to gaseous and cloud attenuation are provided in

Table 1: Atmospheric Budget considering gaseous absorption (oxygen and water vapour), cloud attenuation and rain attenuation.

	X-band Polar	X-band - Europe	X-band - Tropics	Ka-band Polar	Ka-band-Europe	Ka-band Tropics
Rain Characteristics	no rain	2 mm - 4 km	5 mm - 4 km	no rain	2 mm - 4 km	5 mm - 4 km
Losses [dB]						
Gaseous absorption	0,18	0,18	0,266	1,05	1,05	2,04
Clouds attenuation	0,051	0,051	0,255	0,62	0,62	3,11
Losses excluding rain	**0,231**	**0,231**	**0,521**	**1,67**	**1,67**	**5,15**
Rain attenuation	none	0,267	0,815	none	6,89	15,71
Total losses [dB]	**0,231**	**0,489**	**1,336**	**1,67**	**8,56**	**20,86**

4. Probability of rain events

Depending on the location on Earth, the probability for precipitation events differs to a large extent. At higher latitudes and especially at the polar region the probability is extremely low. Thus, it is valid to conclude that only gaseous attenuation and cloud/fog attenuation will contribute to the atmospheric attenuation budget for polar regions. For non-polar regions such as Europe, the influence of attenuation due to rain has to be taken into account for a certain amount of data which is far less than 10 %. In order to show how frequently measurements will be effected, pertaining statistical information is provided in the figure below.



A depiction of the annual probability versus path attenuation for three different climatic regions. These are Tropical, Central Europe and polar regions (like Greenland). The probability for rain in polar regions is negligible. However for mid-latitudes and tropical regions rain may be present to a certain extent.

5. Summary and Conclusions

- The **atmospheric budget for different, characteristic regions** and **with respects to different contributions** has been presented.
- Attenuation due to **heavy rain events** has been identified as **main potential reason for image degradation** and artefacts in the case of X- and especially at Ka band frequencies.
- **Clouds with little water liquid content**, low rain rates and homogenous distribution will cause **no or little disturbance** (visible artefacts) and a power margin should be sufficient for remedial action.
- Ka-band measurements even under low rain intensity are beyond 100 % of operational reality.
- For simple mitigation of rain attenuation a second acquisition is an ultimate alternative because of the fact that rain events are highly localized in time and space.

References.:

A. Danklmayer, B. Döring, M. Schwerdt, M. Chandra: *Assessment of Propagation Effects in SAR Images*, in IEEE, Transactions on Geoscience and Remote Sensing (TGRS), vol. 47, no. 10, October 2009

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