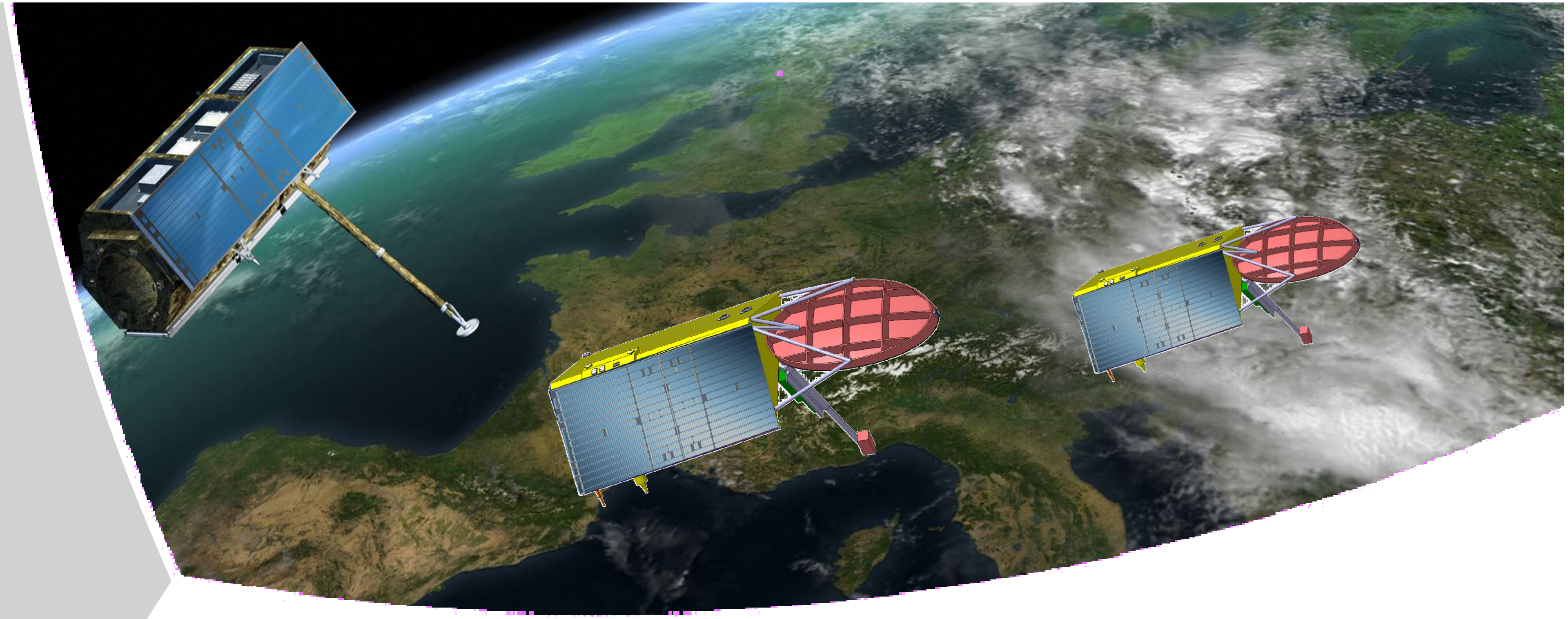

Propagation Effects for Satellite Mounted Radars and Remote Sensing by Active Microwave SAR Sensors for Frequencies of X-band up to Ka-band

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German Aerospace Center (DLR)

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Chemnitz University of Technology *

Chair for Microwave Engineering and Photonics

U.R.S.I.

DLR

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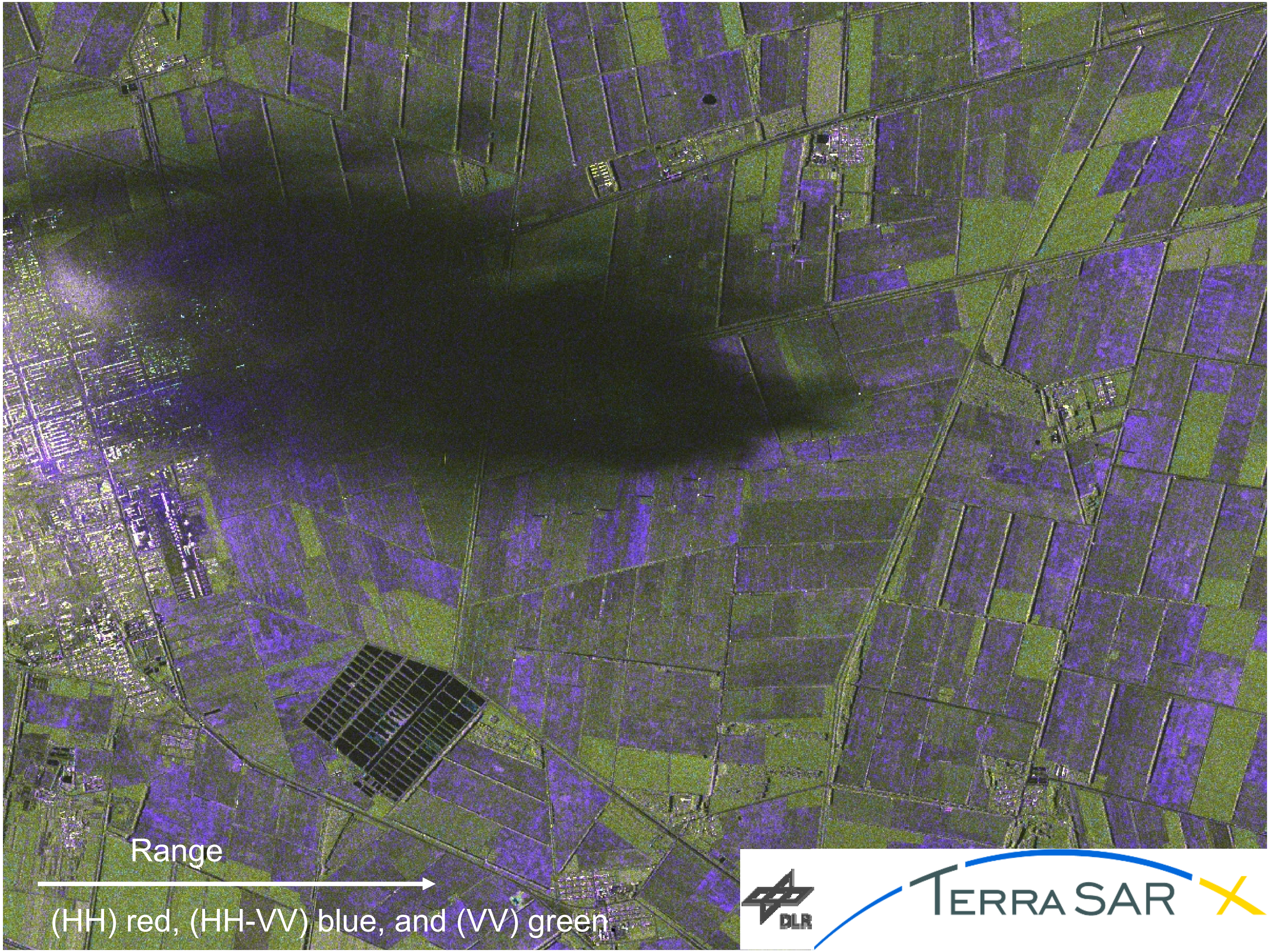
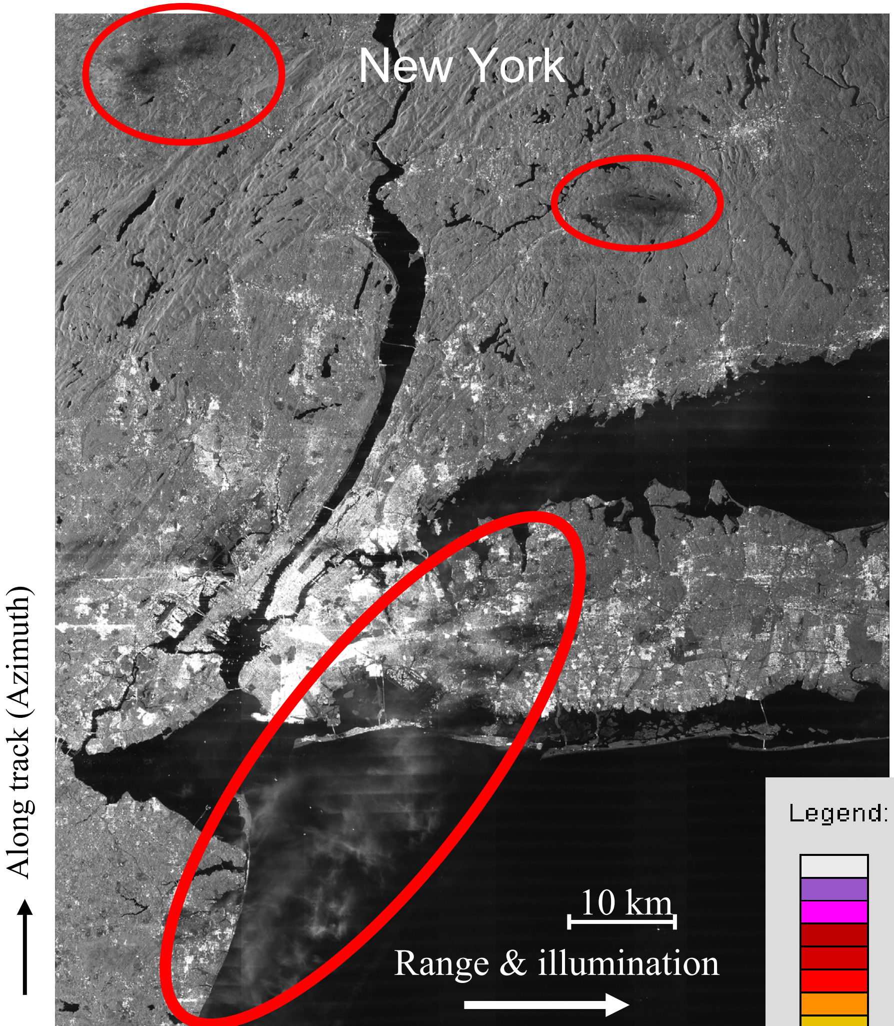
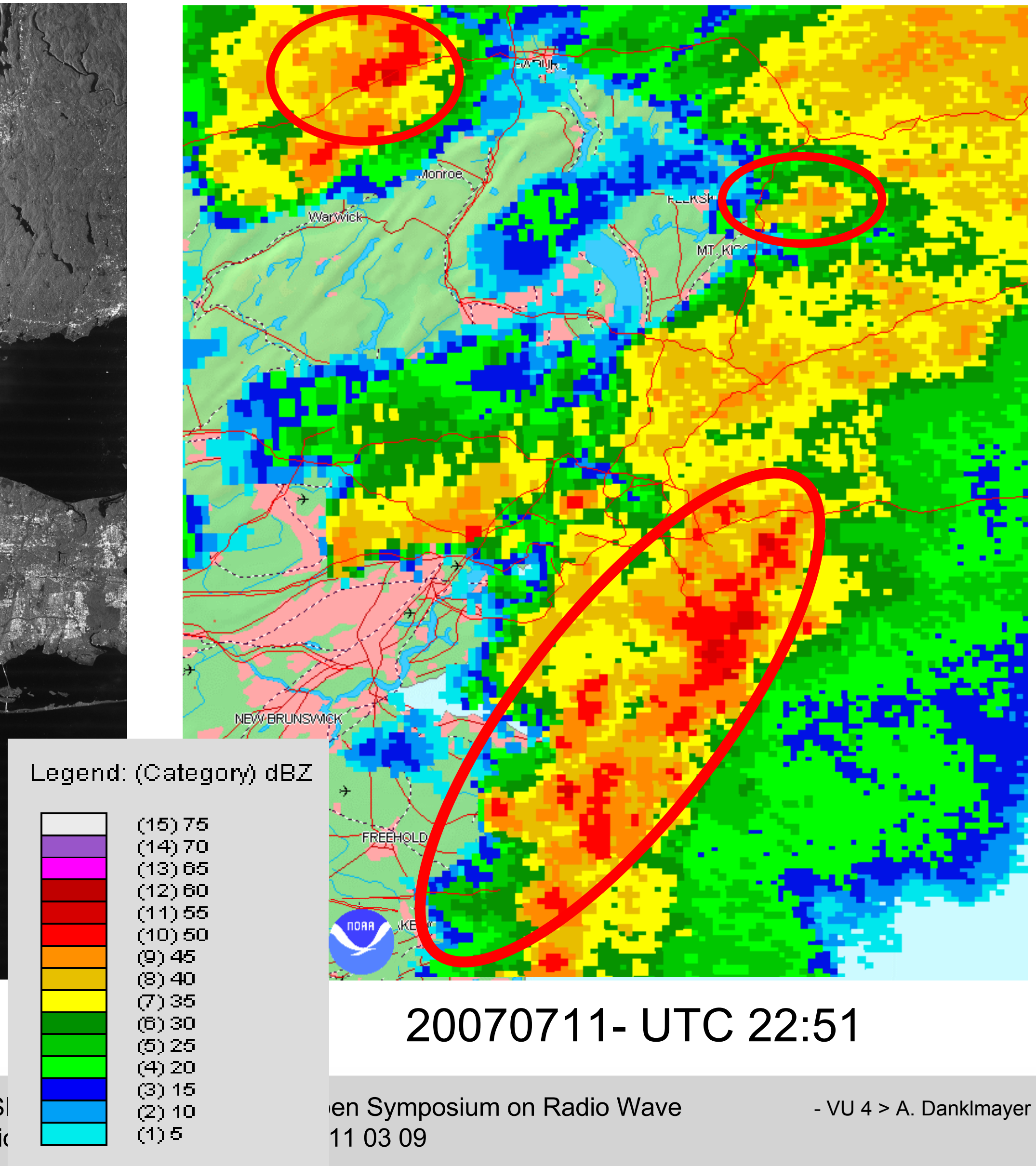
Contents


Range
(HH) red, (HH-VV) blue, and (VV) green
DLR
TerraSAR X

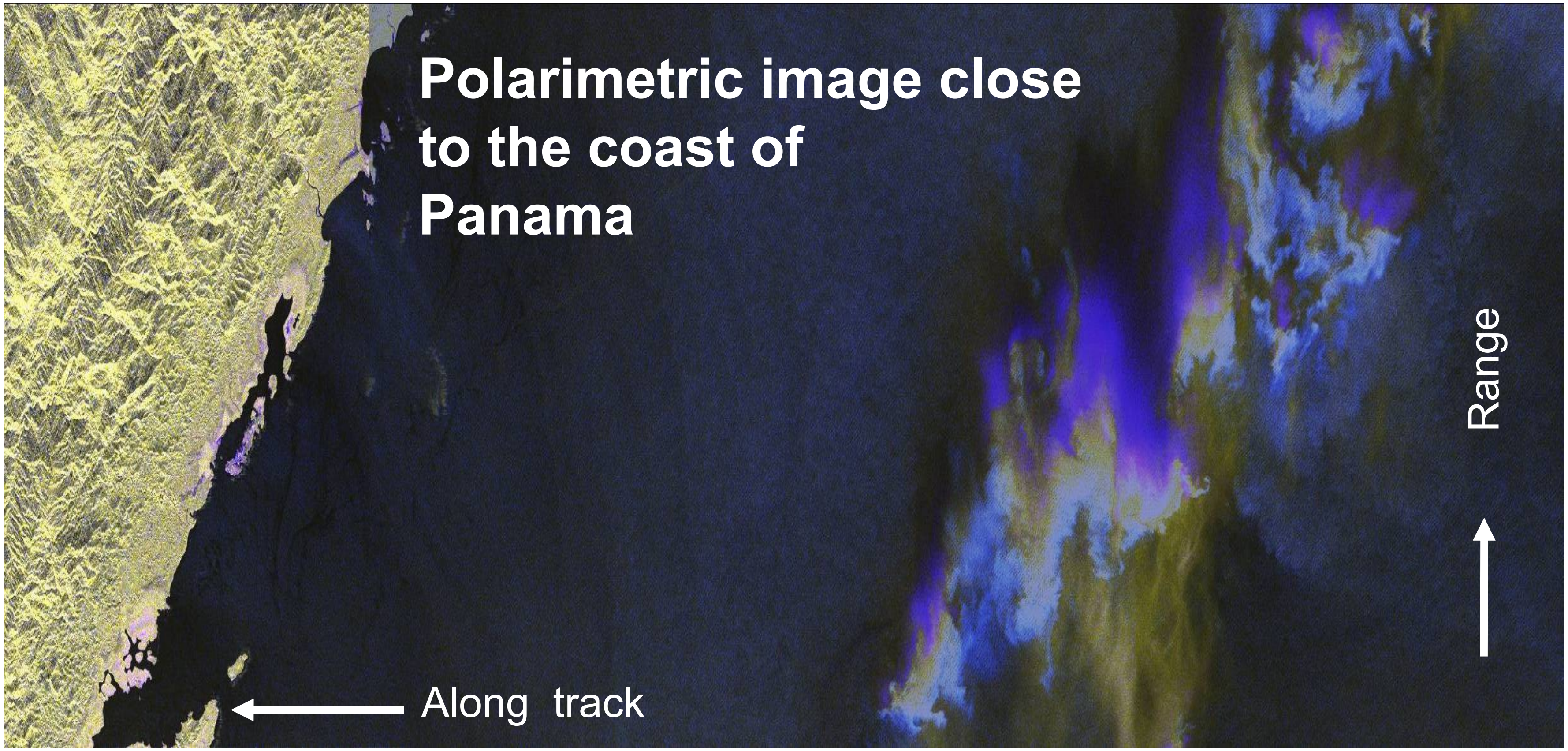
Comparison of TerraSAR-X data with weather radar data



20070711- UTC 22:50

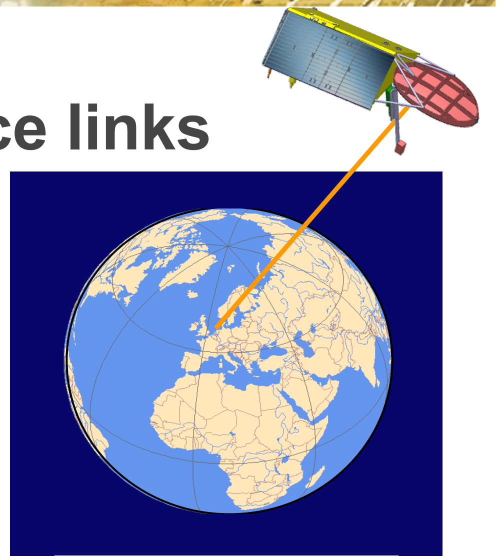


20070711- UTC 22:51



Date	2007-8-11.	**Scene center**	**Lat:** -5,50; **Lon:** -62
Time	9.50. 33.	**Imaging Mode**	Strip map
Image dimensions:		**Polarisation**	HH/VV
Azimuth	~ 60 km	**Red**	HH
Range	~ 30 km	**Green**	VV
Location:	Panama	**Blue**	HH-VV

Attenuation/Absorptions on Earth - space links



- **Gaseous component** (oxygen and water vapour)
  -> always present
  - increases with increasing frequency, windows
  - 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.

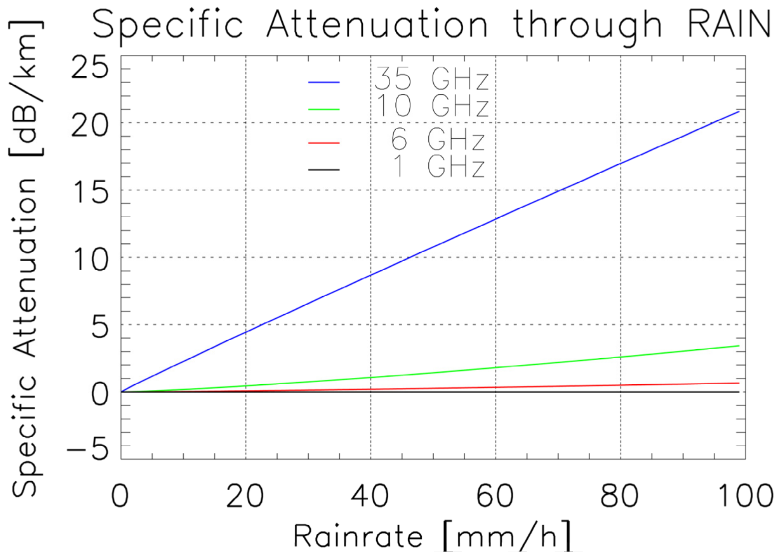
- ***Clouds and fog:*** much less severe than rain, however present much larger percentage of time than rain

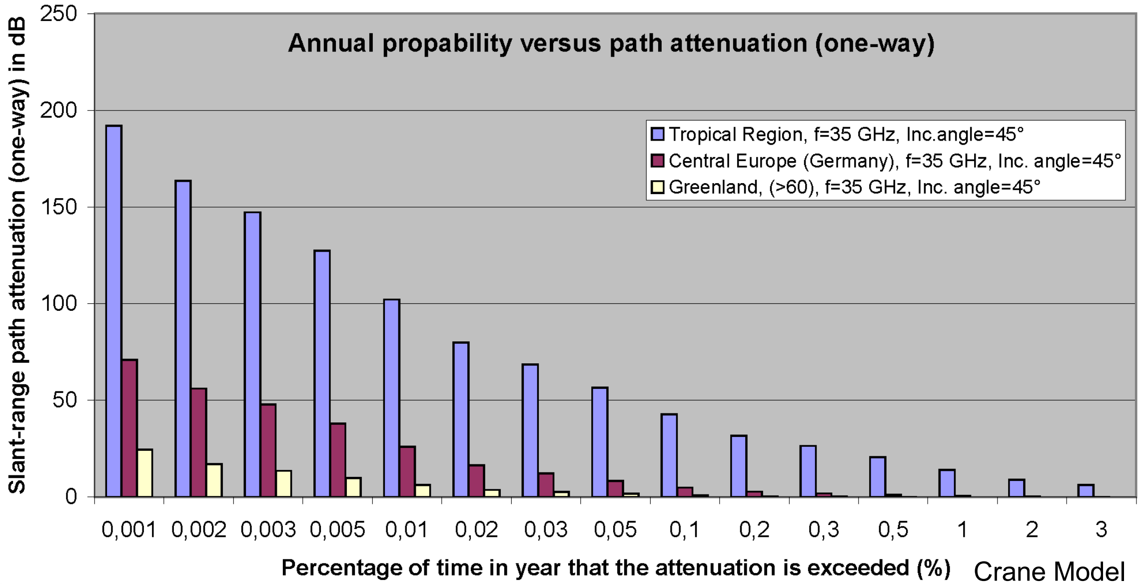
- Note: The lower the elevation angles the more attenuation becomes significant

Annual probability versus slant path attenuation

Annual probability		Attenuation	
0,001	%	28,91	dB
0,002	%	20,73	dB
0,003	%	16,81	dB
0,005	%	12,65	dB
0,01	%	8,25	dB
0,02	%	5,13	dB
0,03	%	3,79	dB
0,05	%	2,51	dB
0,1	%	1,34	dB
0,2	%	0,64	dB
0,3	%	0,39	dB
0,5	%	0,18	dB
1	%	0,049	dB
2	%	0,003	dB
3	%	0	dB
5	%	0	dB

→ „No rain – no rain attenuation assumption“

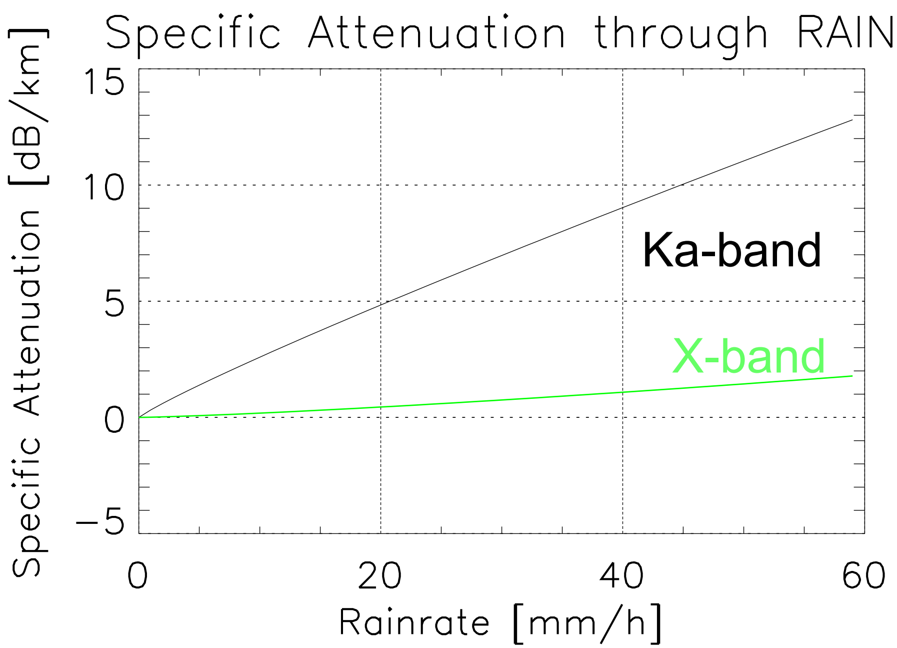




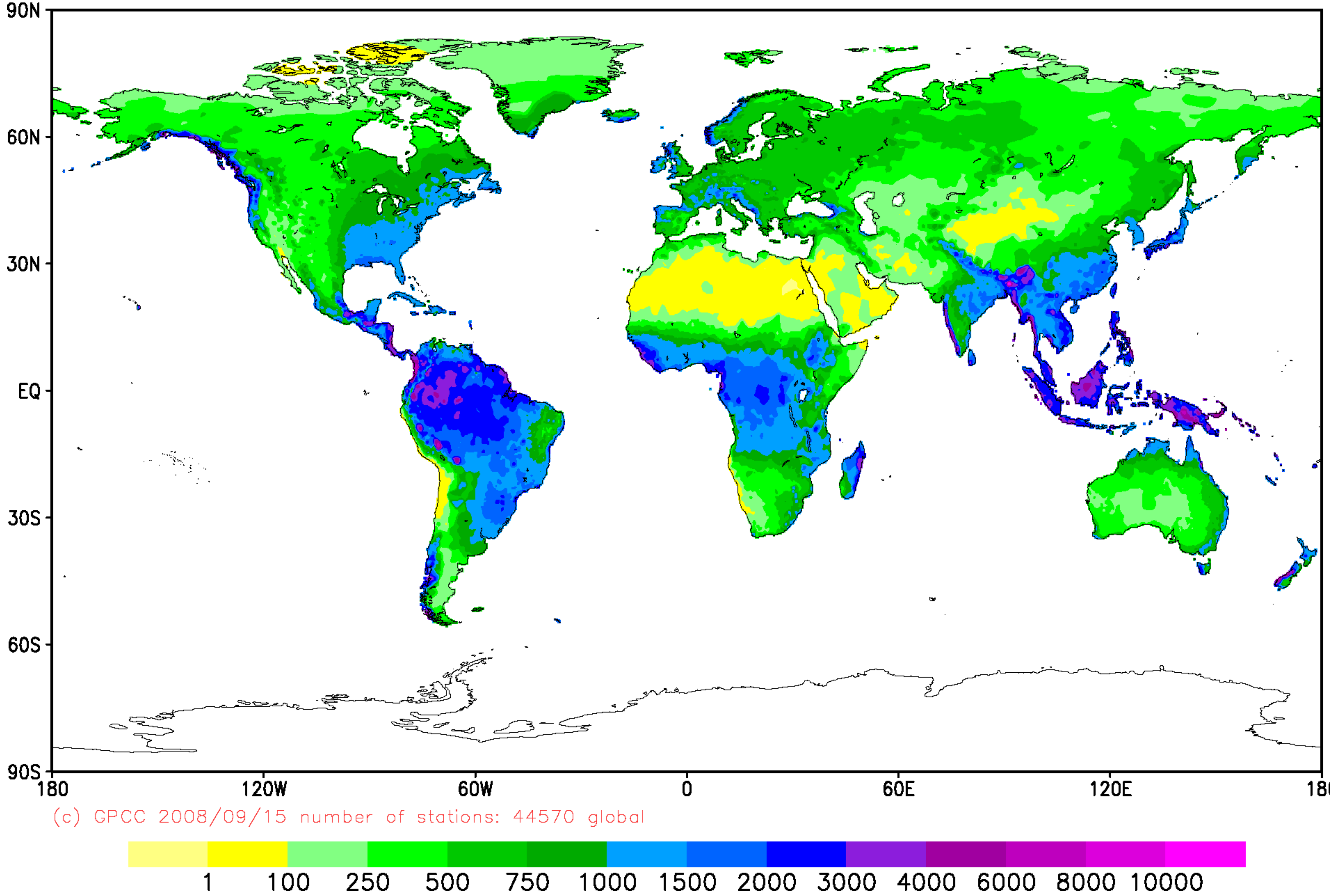
Crane Model

Specific Attenuation through rain

Rainrate [mm/h]	Specific Attenuation [dB/km]	
	X-band (9,6 GHz) V- Pol	Ka-band (35 GHz) V-Pol
0	0	0
1	0.010	0.33
2	0.024	0.61
3	0.039	0.88
4	0.055	1.14
5	0.072	1.39
10	0.167	2.59
20	0.389	4,84
30	0.637	6.97
40	0.904	9.03
50	1.186	11.04



GPCC Precipitation Normals in mm/year per 0.25 degree grid for YEAR

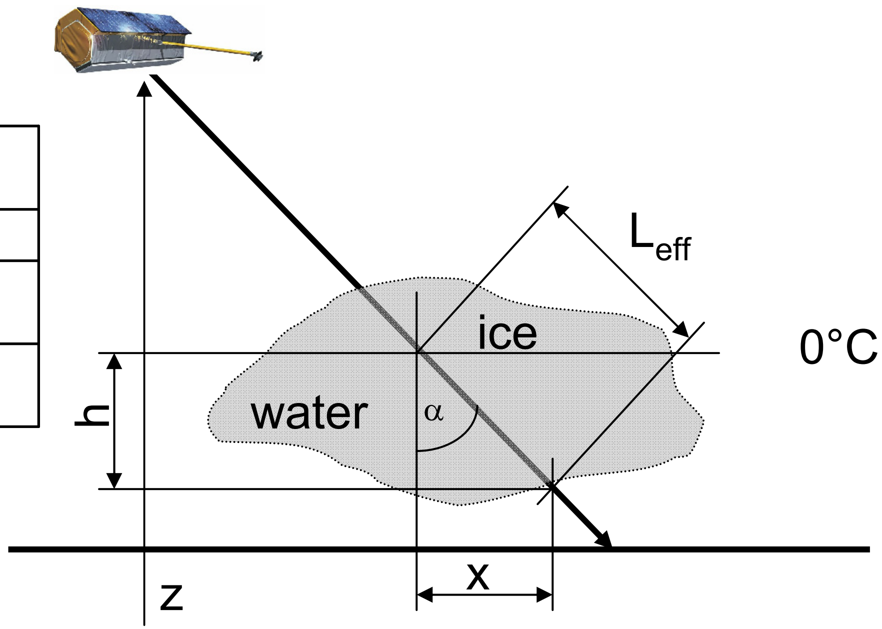


Modelling of Rain attenuation

- $A = l_{eff}\, a(f) R^{b(f)}$

Table I. Regression coefficients for estimation of the rain attenuation

Frequency	Drop size Distribution (DSD) Marshall Pallmer		Joss Thunderstorm	
	A	**b**	**A**	**b**
X – band (10 GHz)	0.0136	1.15	0.0169	1.076
Ka- band (35 GHz)	0.268	1.007	0.372	0.783

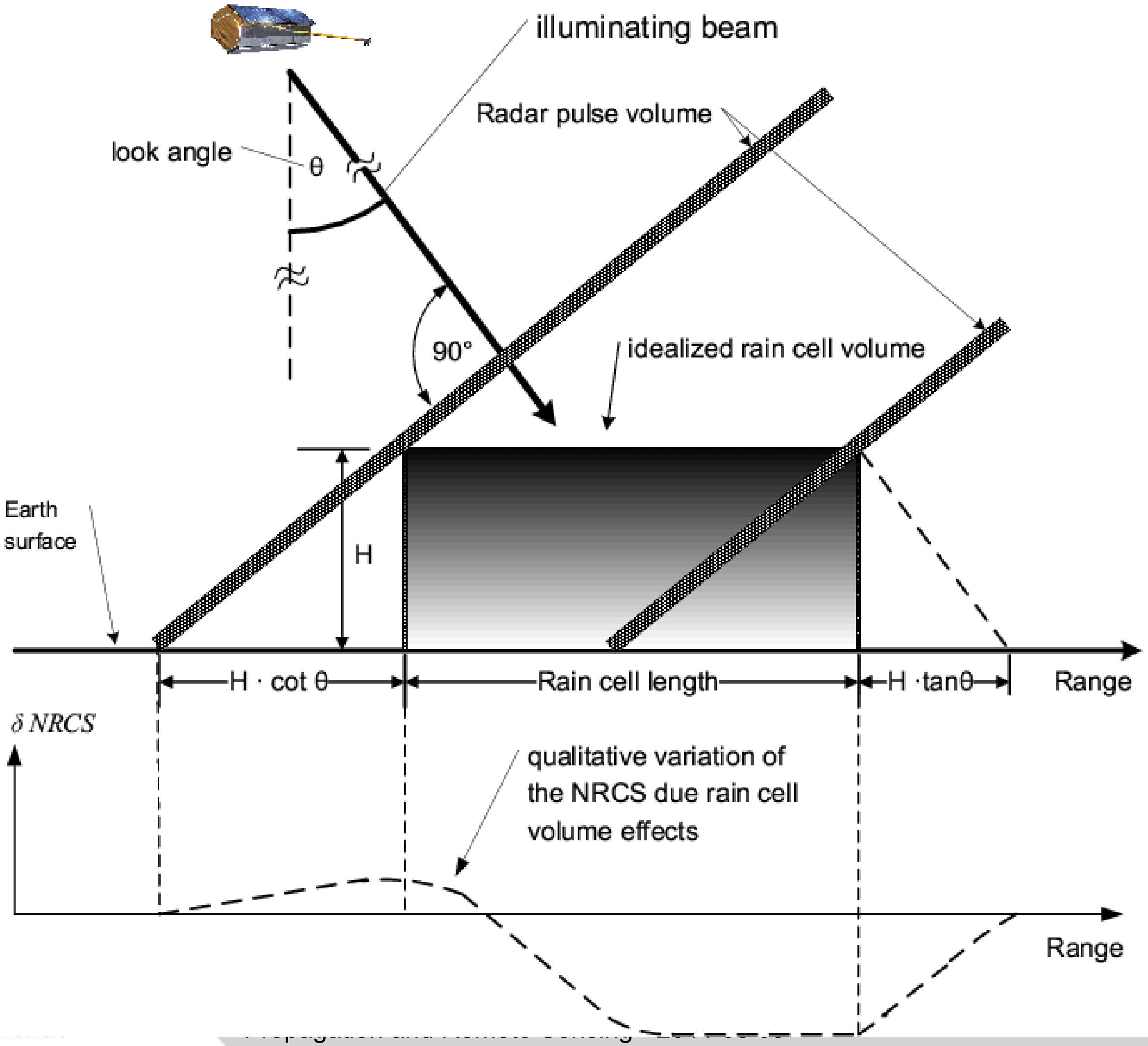


R: rain rate(mm/h)
leff: effective pathlength (km)
a, b: frequency, DSD, etc. dependent coefficients

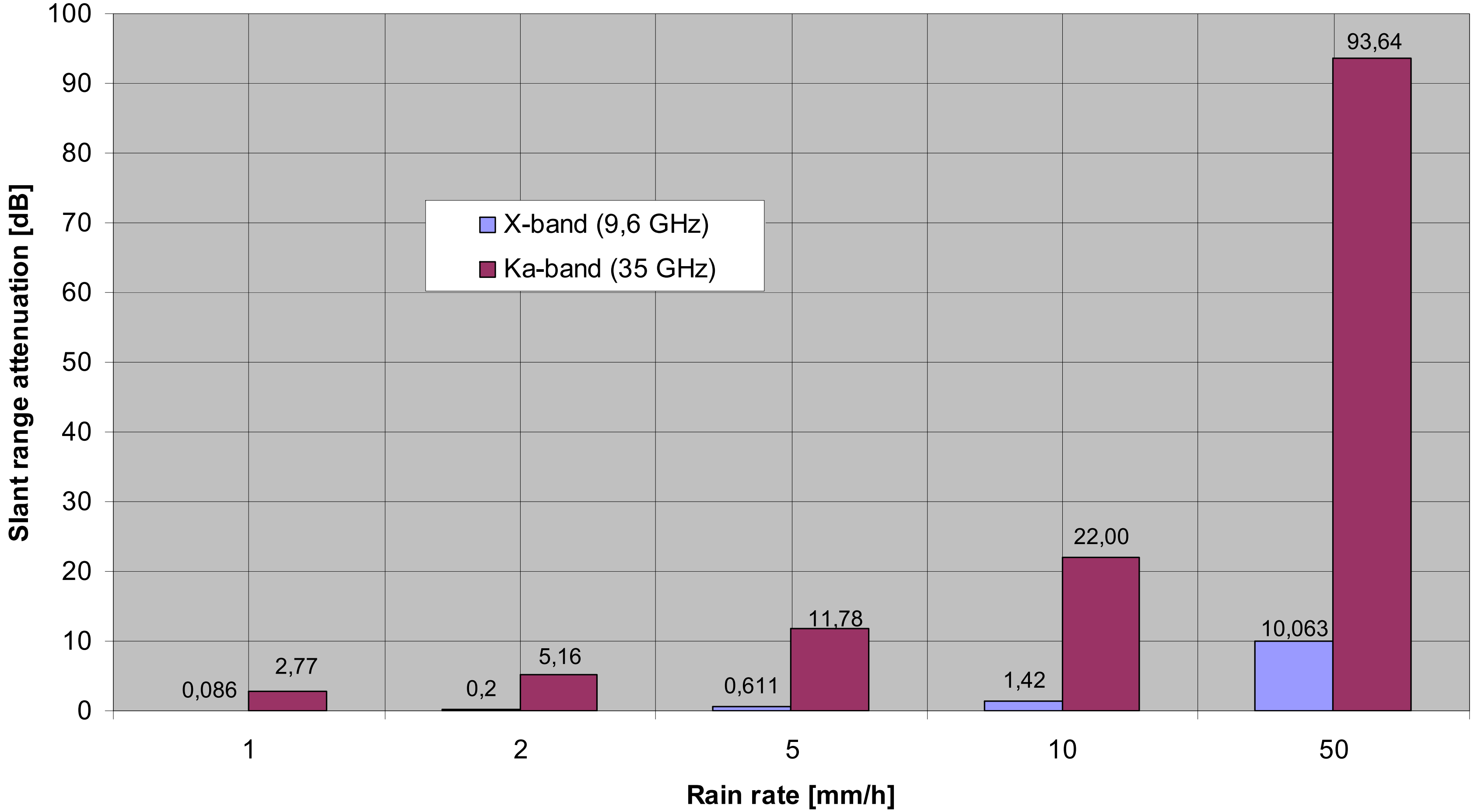
Table II. Rain rate [mm/hr] and specific attenuation [dB/km] for the X- and Ka-band frequencies

Rain intensity [mm/hr]	Specific Attenuation [dB/km]	
	X-band @10 GHz	**Ka-band @35 GHz**
5	0.08	**1.31**
50	**1.22**	7.95
100	2.4	13.69

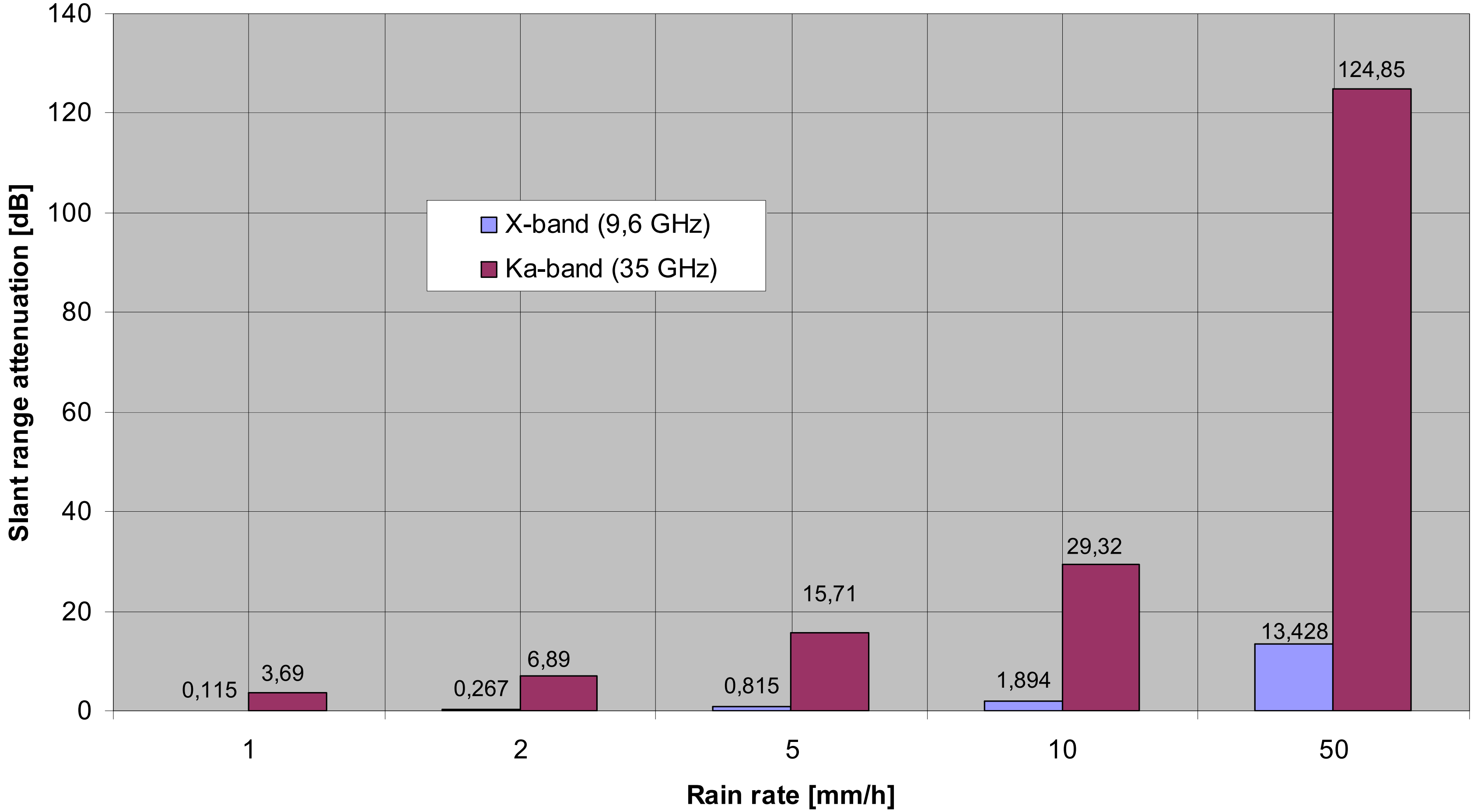
SAR imaging geometry for the modelling of precipitation effects in SAR imaging



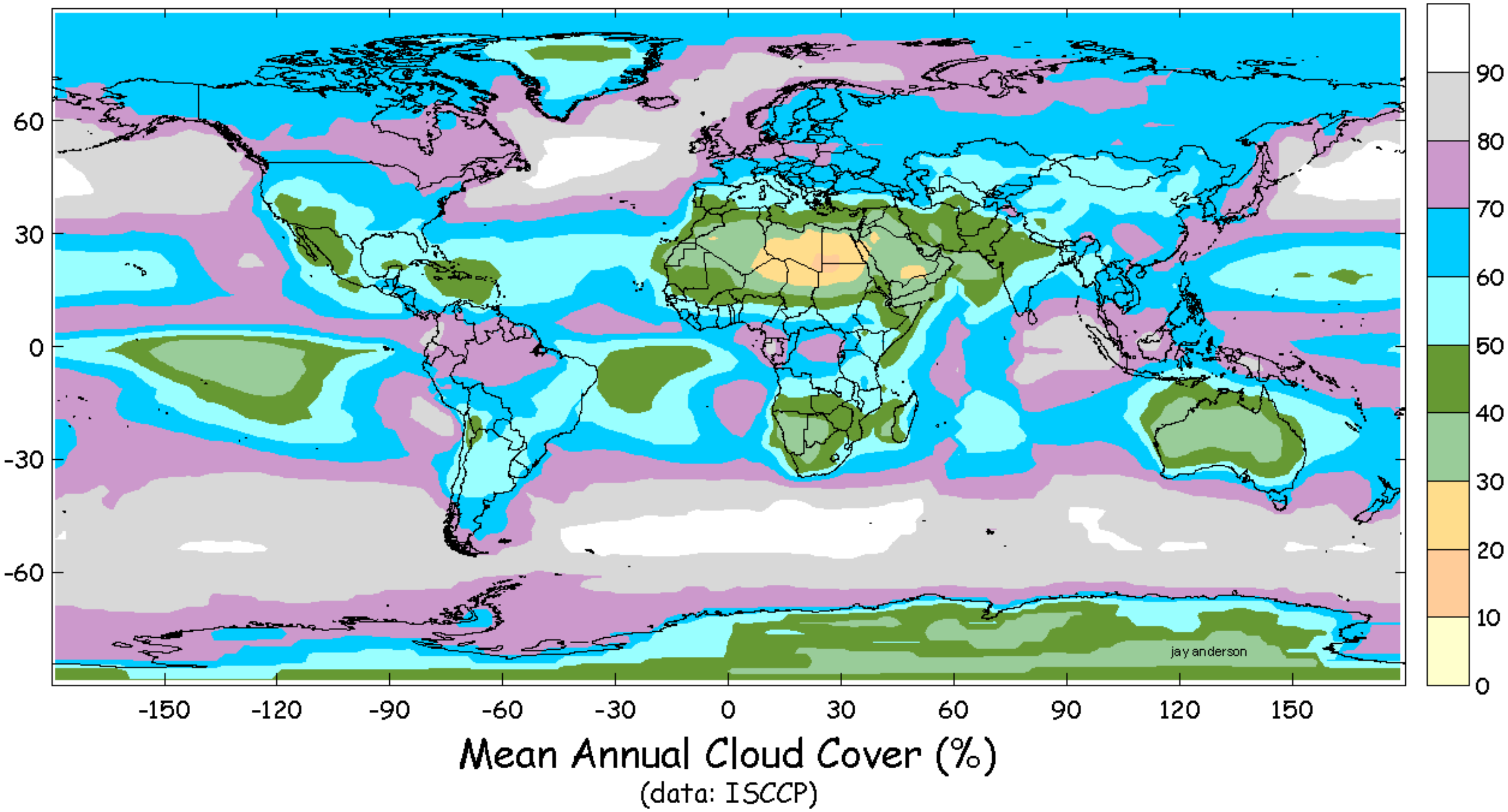
Two-way slant-range Attenuation [dB] through rain vs. rain rate [mm/h] at 45° incidence angle - 3 km rain height



Two-way slant-range Attenuation [dB] through rain vs. rain rate [mm/h] at 45° incidence angle - 4 km rain height



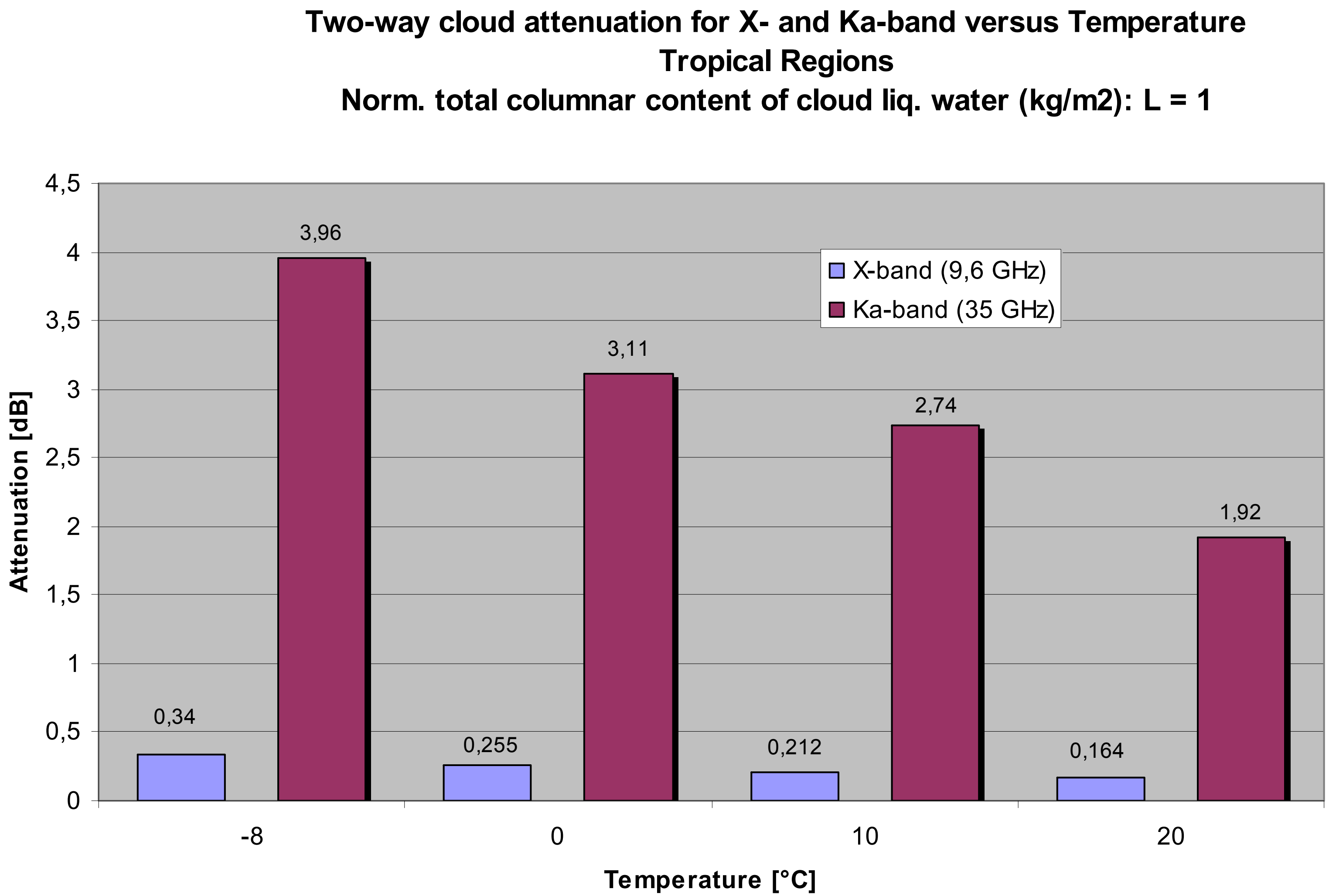
Mean Annual Cloud Cover Map

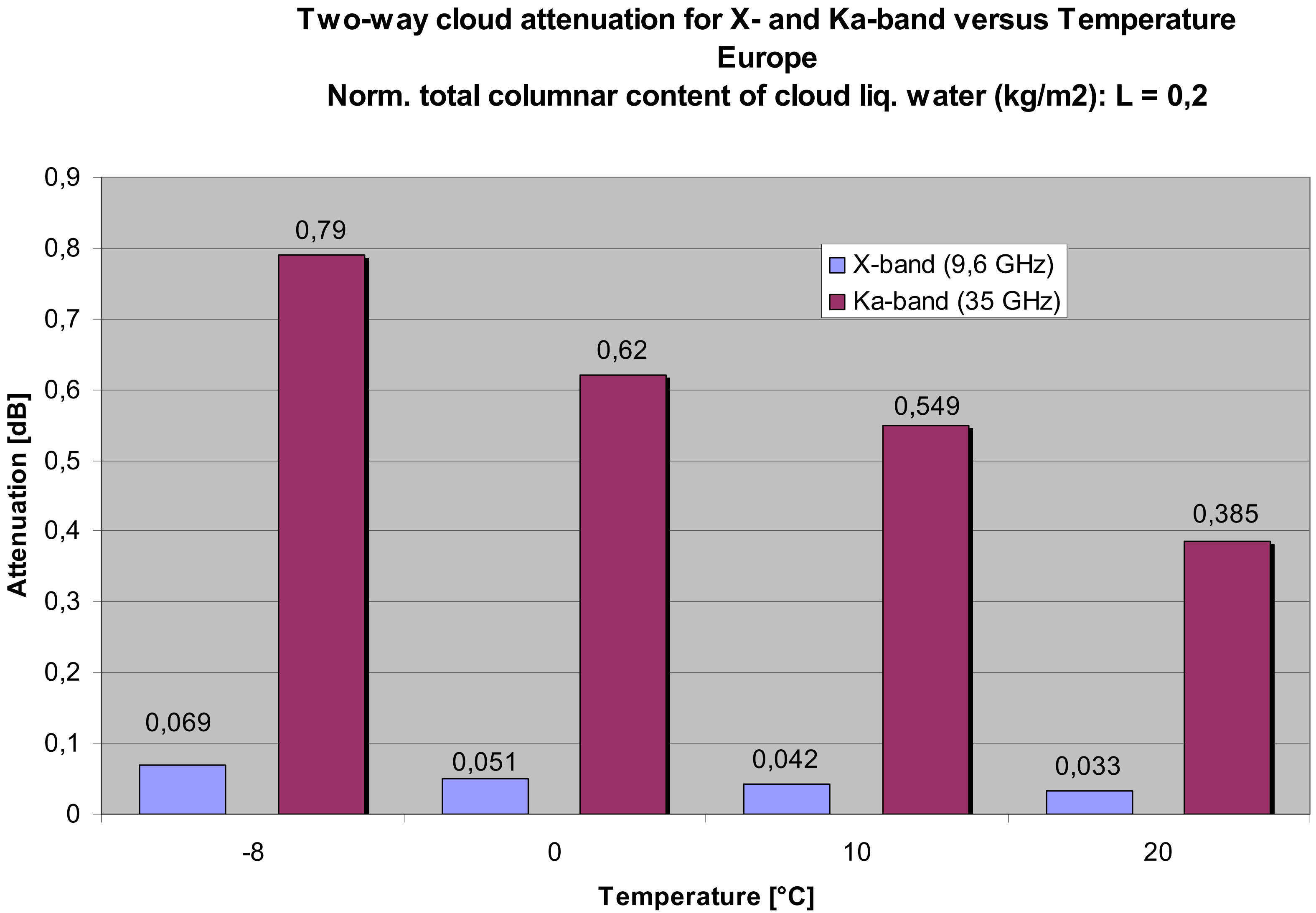


Global average ~ 50%

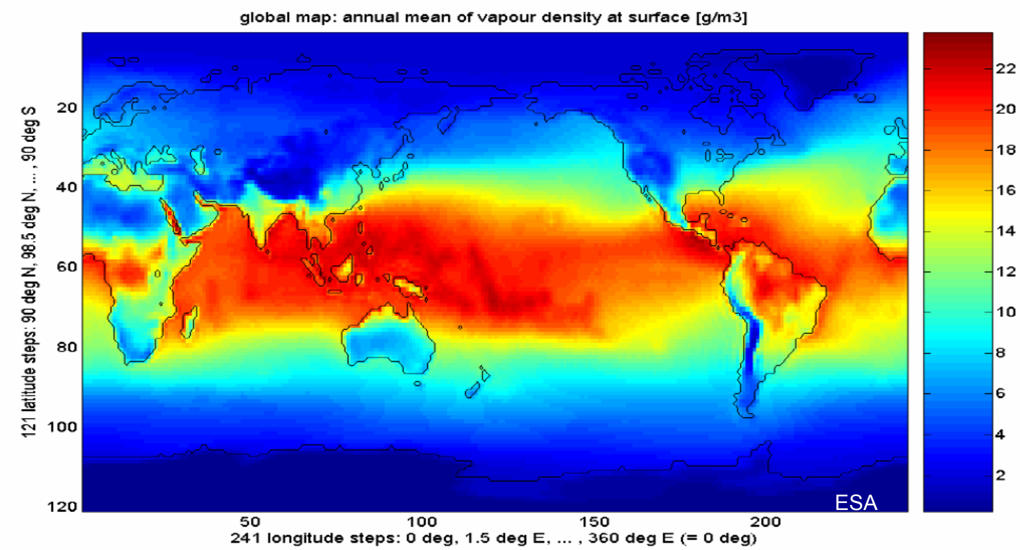
http://isccp.giss.nasa.gov/index.html

Two way cloud attenuation

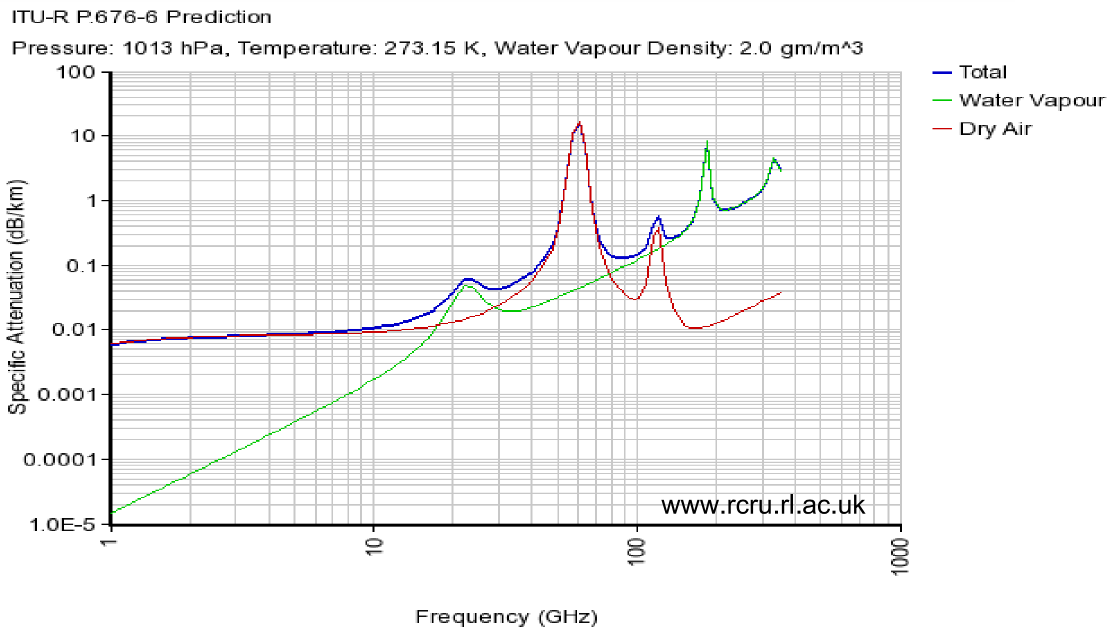



Two-way cloud attenuation for X- and Ka-band versus Temperature
Europe
Norm. total columnar content of cloud liq. water (kg/m2): L = 0,2
Attenuation [dB]
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,79
0,62
0,549
0,385
0,069
0,051
0,042
0,033
X-band (9,6 GHz)
Ka-band (35 GHz)
-8
0
10
20
Temperature [°C]

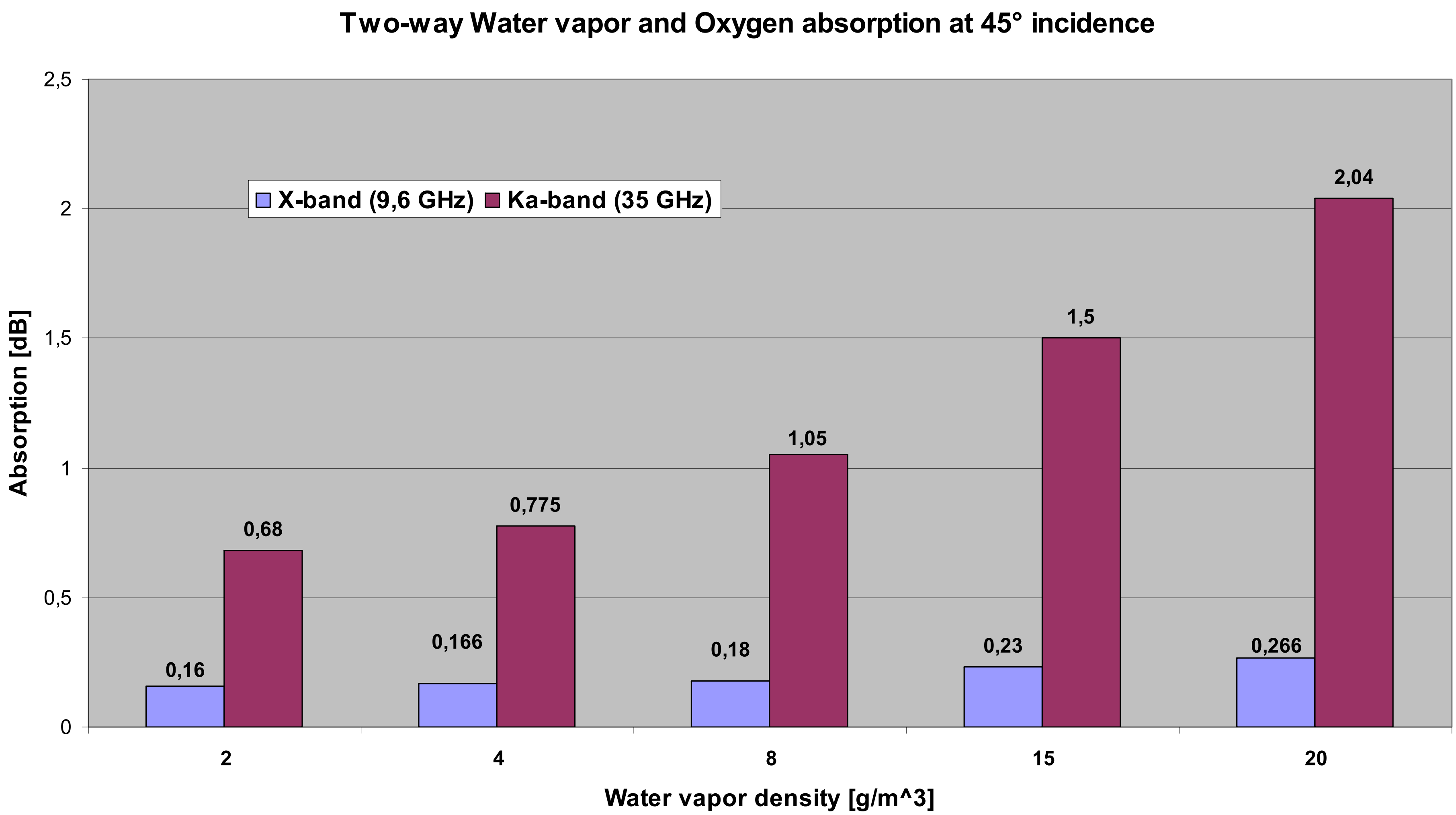
Water vapor and oxygen absorption



ITU – R P.676-3 (1997)/
ITU – R P.676-6



Deutsches Zentrum für Luft- und Raum
in der Helmholtz-Gemei
DLR


Two-way Water vapor and Oxygen absorption at 45° incidence
X-band (9,6 GHz)
Ka-band (35 GHz)
Absorption [dB]
2,5
2
1,5
1
0,5
0
0,16
0,68
0,166
0,775
0,18
1,05
0,23
1,5
0,266
2,04
2
4
8
15
20
Water vapor density [g/m^3]

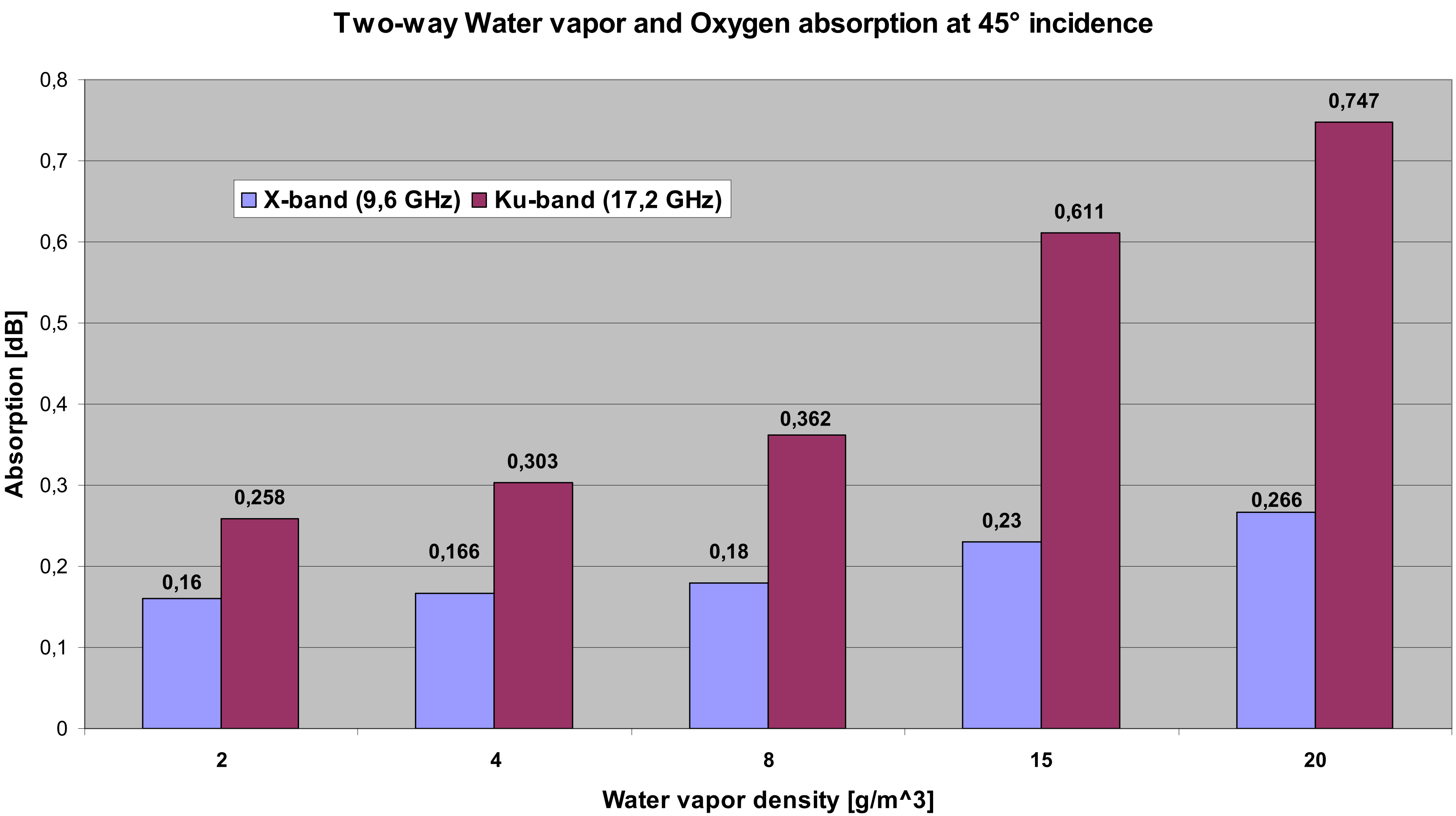
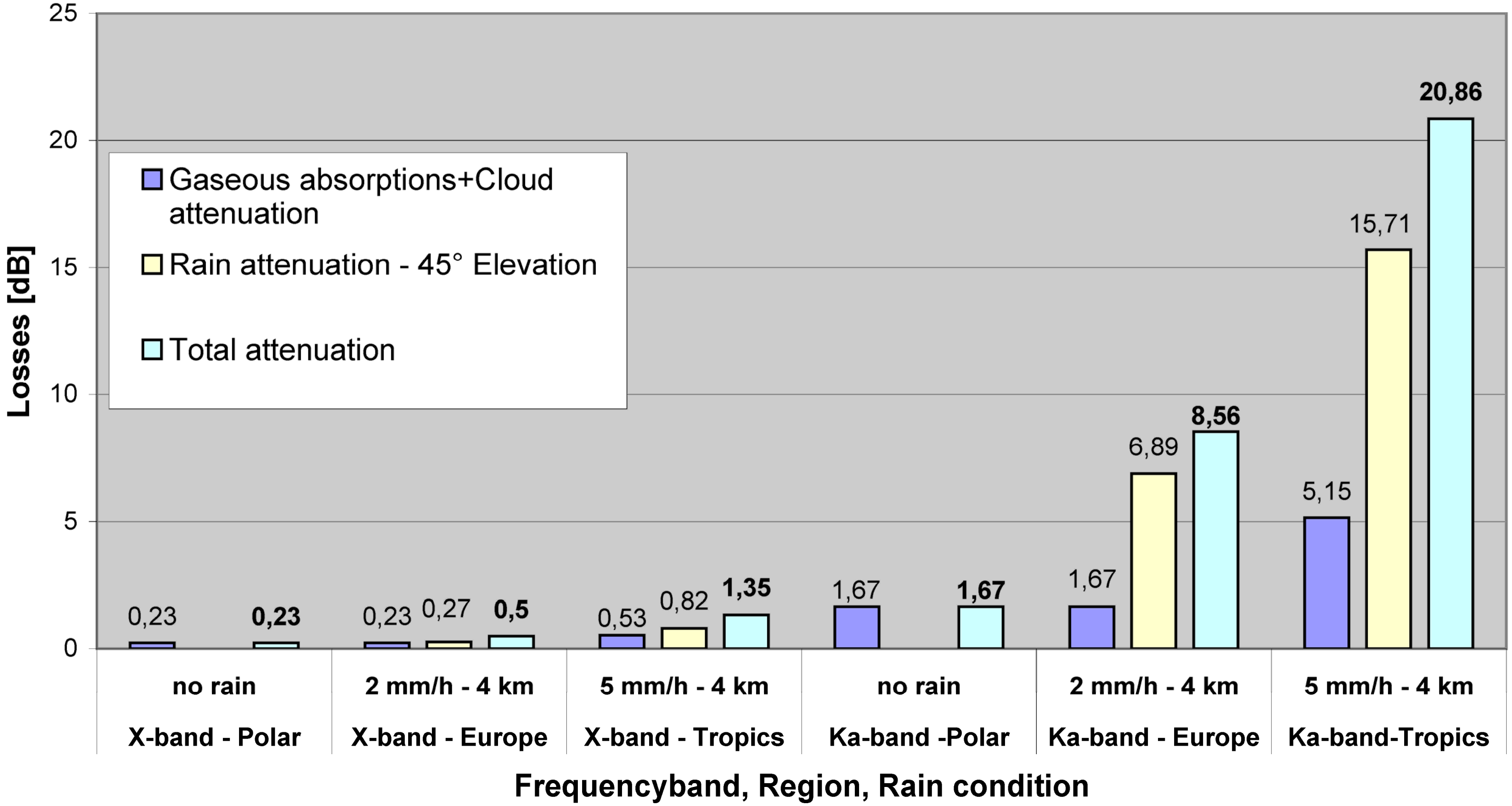

Two-way Water vapor and Oxygen absorption at 45° incidence
X-band (9,6 GHz)
Ku-band (17,2 GHz)
Absorption [dB]
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,16
0,258
0,166
0,303
0,18
0,362
0,23
0,611
0,266
0,747
2
4
8
15
20
Water vapor density [g/m^3]

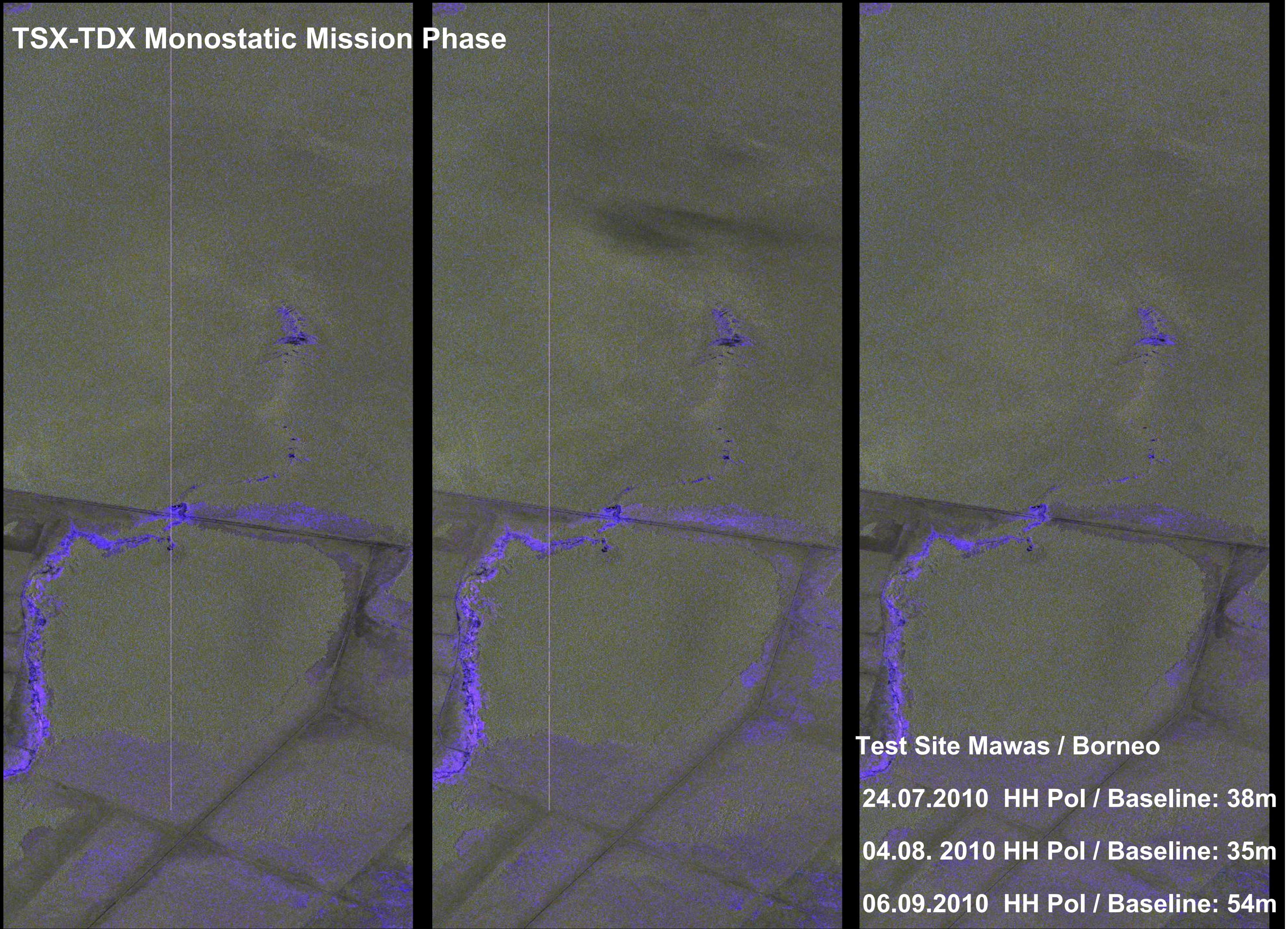
Table of atmospheric losses

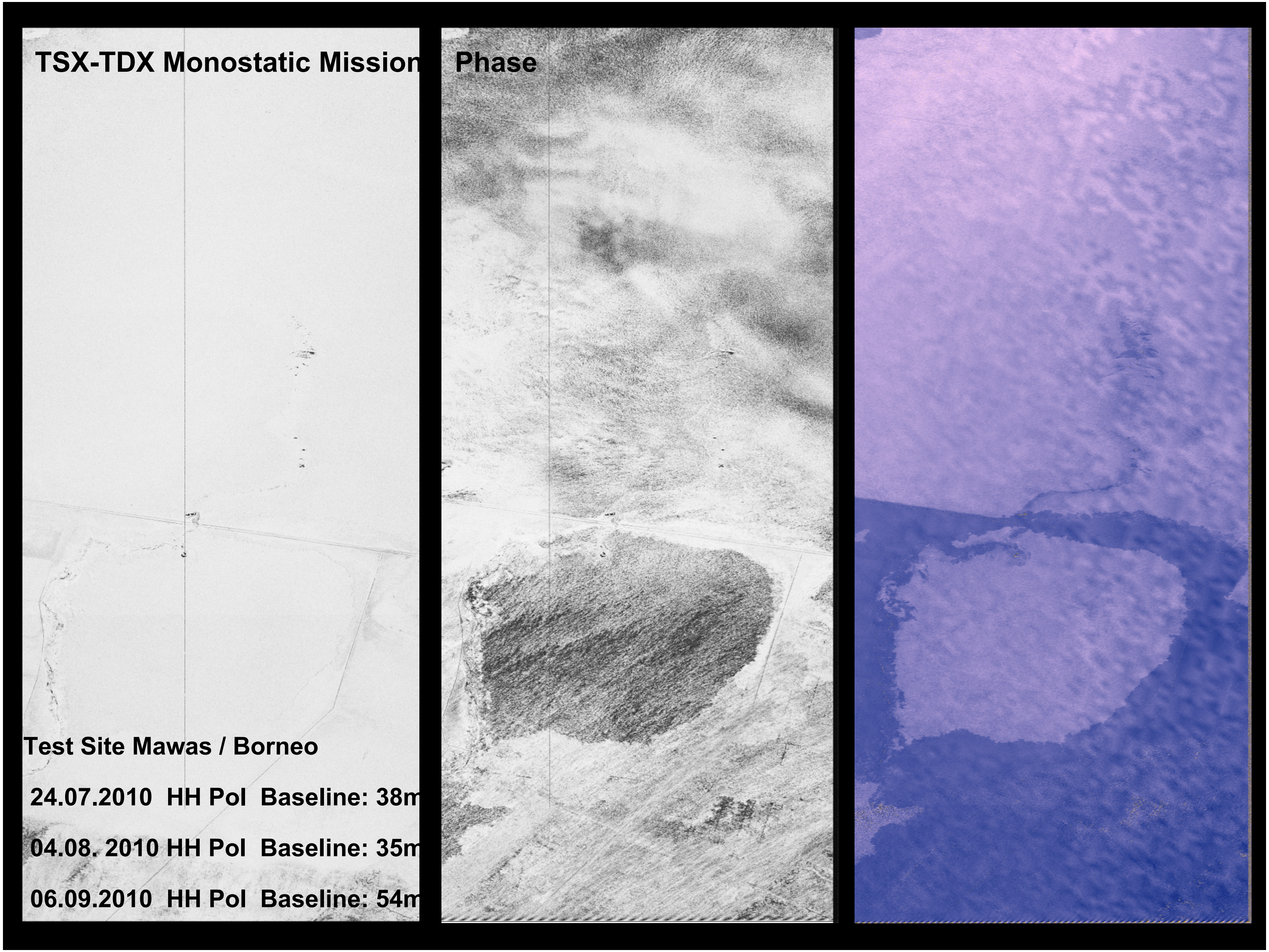
	X-band Polar	X-band - Europe	X-band - Tropics	Ka-band Polar	Ka-band- Europe	Ka-band Tropics
Rain Characteristics	no rain	2 mm - 4 km	5 mm - 4 km	no rain	2 mm - 4 km	5 mm - 4 km
Losses [dB]						
Gaseous absorption	0,18	0,18	0,266	1,05	1,05	2,04
Clouds attenuation	0,051	0,051	0,255	0,62	0,62	3,11
Losses 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**

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

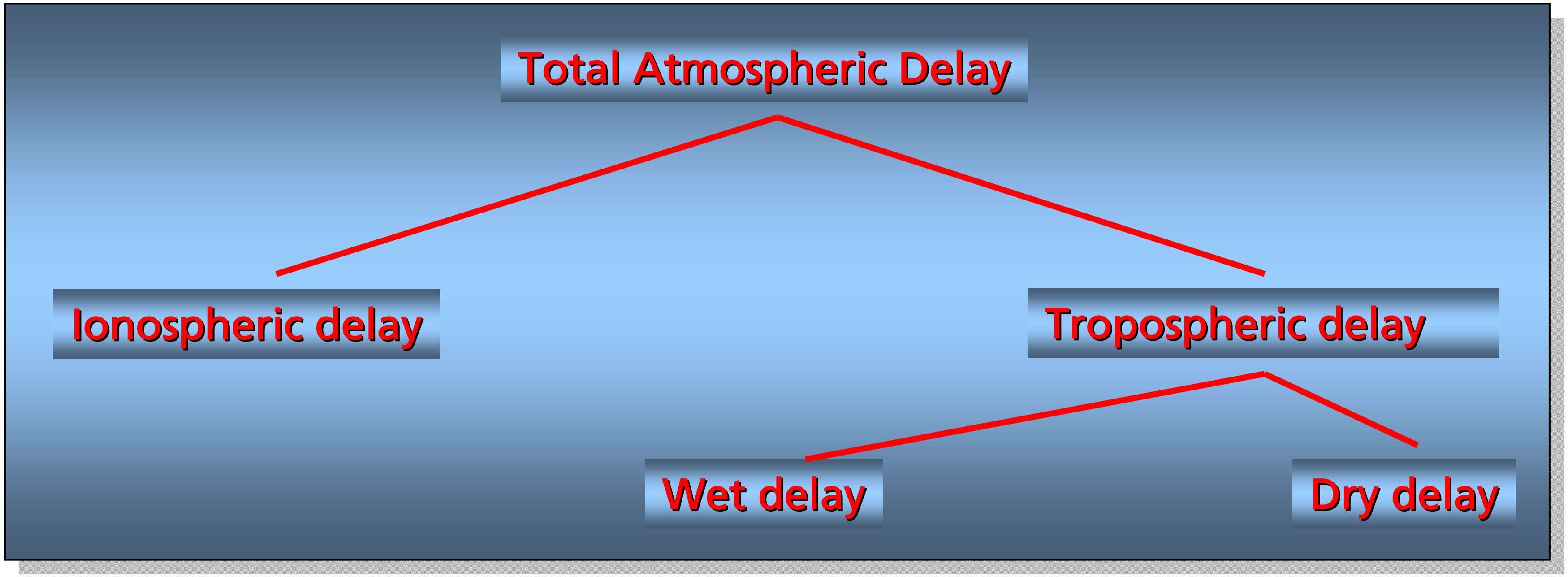


TSX-TDX Monostatic Mission Phase




TSX-TDX Monostatic Mission
Phase
Test Site Mawas / Borneo
24.07.2010 HH Pol Baseline: 38m
04.08. 2010 HH Pol Baseline: 35m
06.09.2010 HH Pol Baseline: 54m

Total atmospheric delay

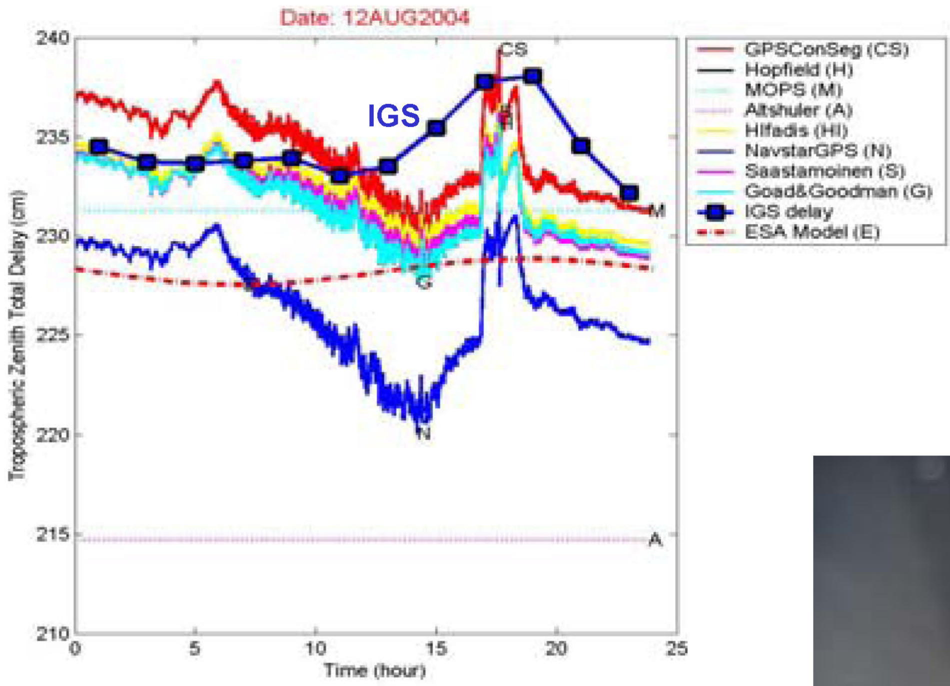


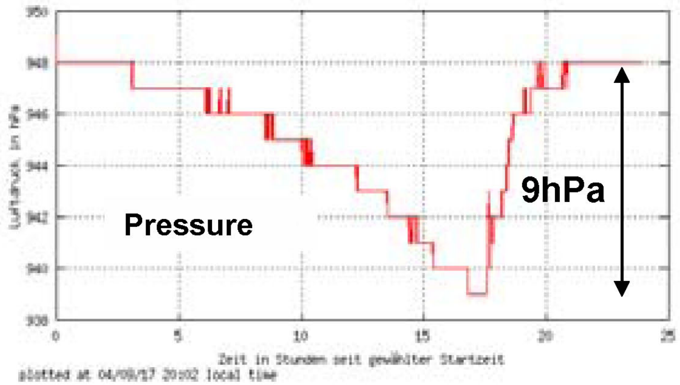
- Wet delay about 10% of the total delay, max. 50-80 cm, typically 10-20 cm: changes between several hours and distances of 10 km 10-20%
- Dry delay 90% = 230 cm one way: very stable and changes between several hours only 1 %

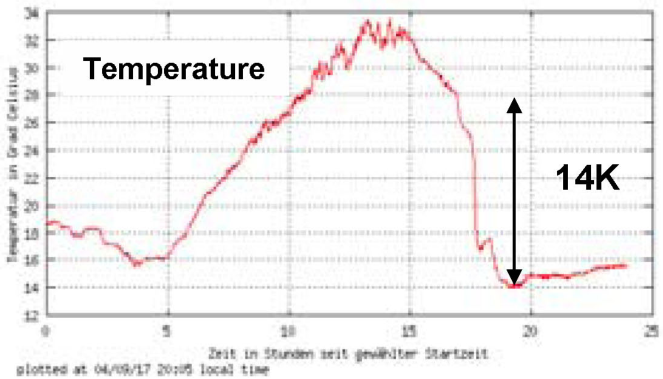
Further `non`- atmospheric phase effecting factors

- Temporal decorrelation of the scatterers i.e. volume decorrelation
- Receiver noise of the SAR Sensor, Processing errors, Orbit errors

Extreme events

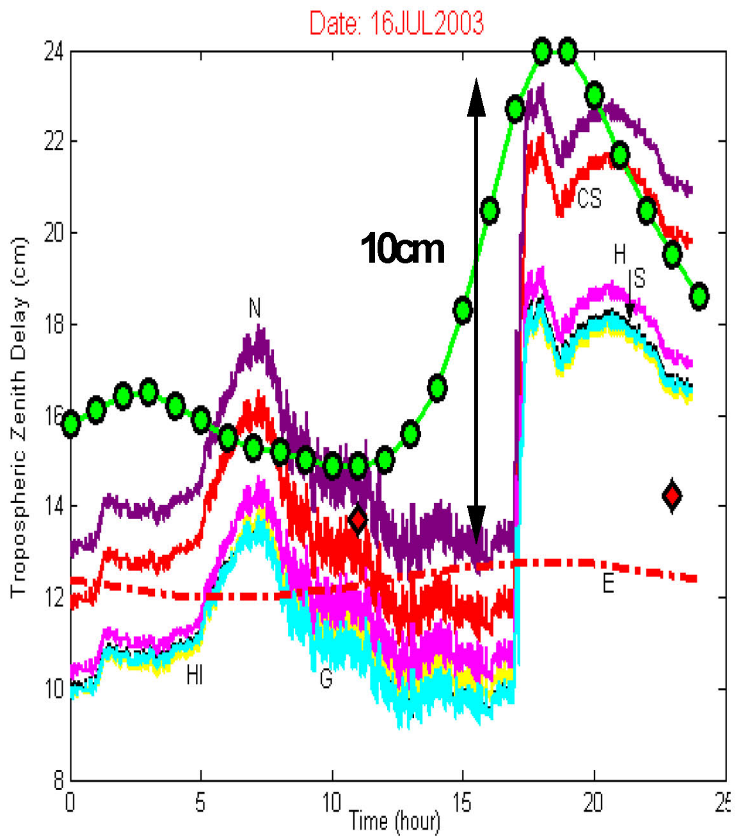




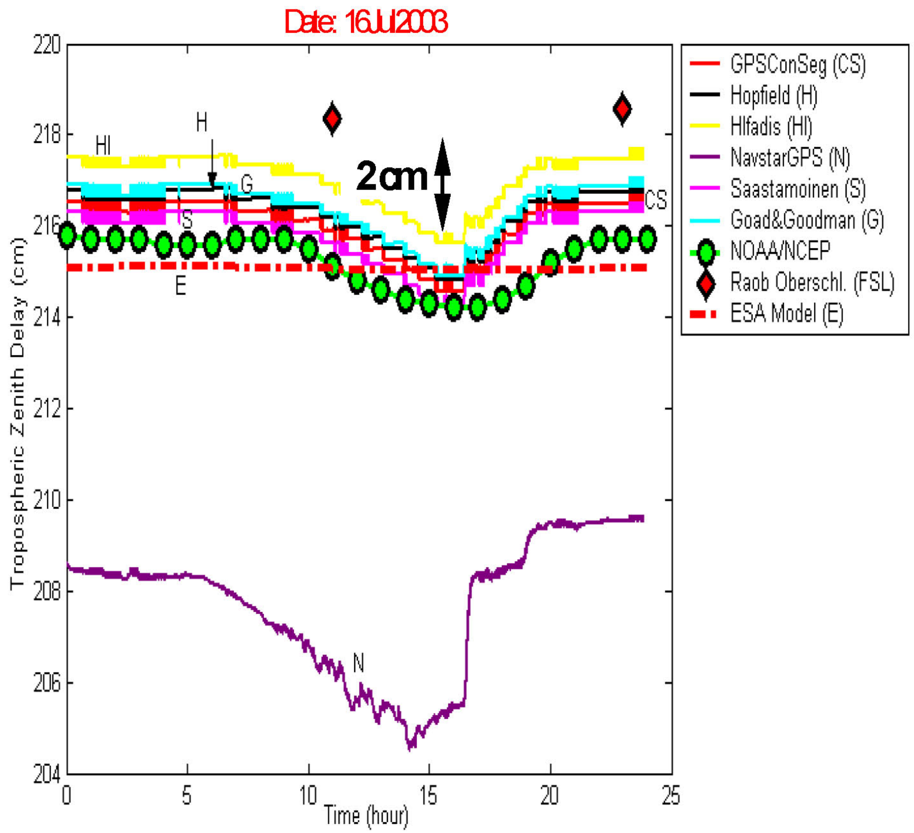


Hornbostel, A. et al DLR - KN

Influence of Local weather events on delay



Wet Delay



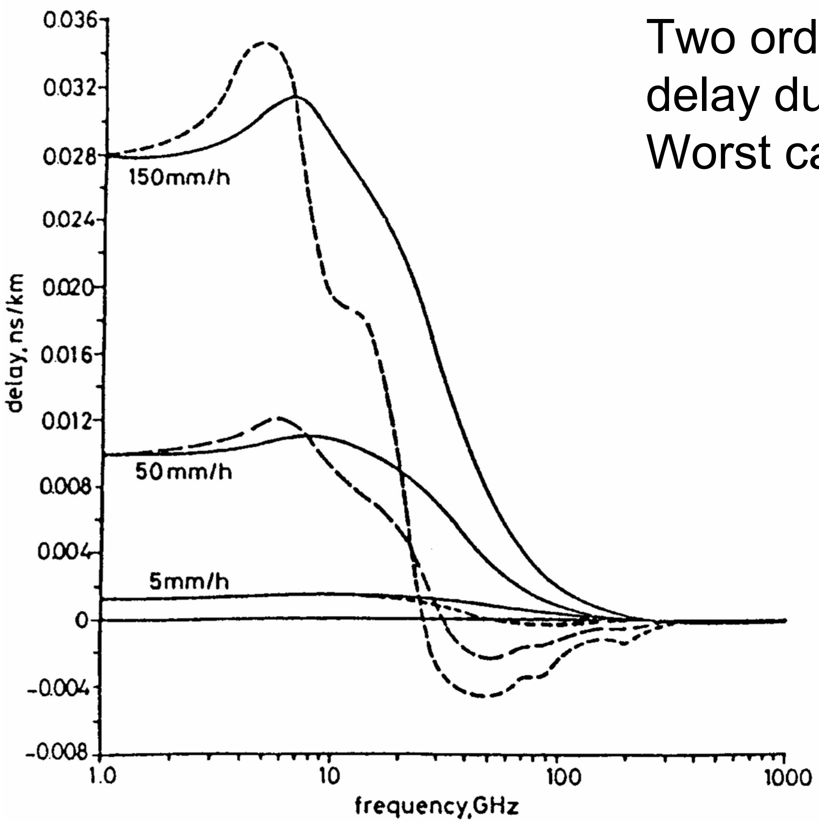
Hydrostatic Delay

Extreme events

- Changes of the tropospheric delay 10 cm during 30‘
- Change/s.: 20 cm /1800 s = 0,0111 cm/s
- 3 s: 0,0333 cm zenith delay; for incidence angle of 37° (cos 37° = 0,799) = 0,0333/0,799 = 0,417 mm
- Reference:

Hornbostel, A. und Hoque, M. M. (2004) *Tropospheric Correction Models for Local Events.* In: Proceedings GNSS 2004 . 8th European Navigation Conference GNSS 2004, Rotterdam, Niederlande, 17-19 Mai, 2004 , Rotterdam, Niederlande.

Specific group and phase delay due to rain



Two orders of magnitude lower than the delay due to gaseous components

Worst case approx. 6 cm extra delay due to rain

----- group delay

—— phase delay

Conclusions

- Changes in the troposphere (pressure, humidity, temperature) within 3 sec. will cause only minor effects in the delay
- 0,033 cm change in the zenith delay during 3 sec: 0,417 mm @ 37°
- Horizontal variations of wet delay between several hours and within 10 km only 10 – 20%
- Dry delay 90% = 230 cm one way: very stable and changes in time between several hours accounts only for 1 %
- Most likely reason for changes in the atmospheric delay which have been observed in images is due to precipitation

Conclusions

- Rain limits performance only to a certain degree in non-polar regions
- Statistical appearance is globally less than 10%
- Acceptable extra margin for gases and cloud/fog losses has to be included in the power budget
- Single pass mode is advantageous compared to dual pass acquisition scenarios
- Apropriate remedial strategies have been identified
- Non-precipiting cloud cover is fully acceptable by including exta margin
- **Second acquisition = ultimate alternative** due to highly localized phenomena of rain both in space and time.
- Atmospheric effects are manageable and will not endanger the successful achievement of any mission objective.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A-2000
Forested
Deforested
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Glacier National Park
USGS
From: Hall and Fagre, 2003
BioScience 53: 131-140
SIMULATION
0 Meters Underwater
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SR 520
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