Ka-Band Propagation Experiment in French Guiana

CNES R&T Study: R-S15/TC-0005-66

April 7th, 2021

ONERA : Xavier Boulanger (until September 2019), Charles-Antoine L'Hour, Jean-Pascal Monvoisin, Laurent Castanet

CNES : Bouchra Benammar, Xavier Boulanger (from September 2019)

CSG : Adrien Lanon, Coline Brunner, Ingrid Epailly

Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

Context of the study

- **Worldwide and central/latin America Ka-band satellite services**
  - INMARSAT GlobalXpress (worldwide) :
    - 5-satellites constellation (since 2019),
    - Broadband telecommunication services
  - EUTELSAT :
    - E65WA (Latin America, since 2016)
    - Coming services for Africa with other satellites

- **Need for characterization of the Earth-space propagation channel**
  - Improvement of prediction models & particularly ITU-R Recommendations
  - System design: link margins & availability assessment: annual, monthly, hourly

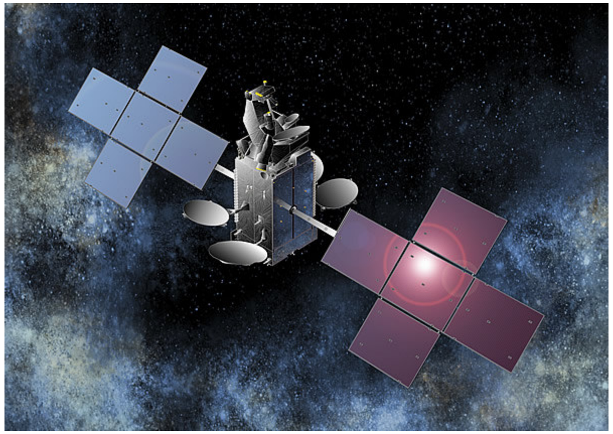
- **Need for measured data with high quality and availability**
  - Parameters to be characterized:
    - Rain and total attenuation, scintillation, sky noise temperature, dépolarization
    - Rainfall rate, ILWC, IWVC
  - Reliable data processing: validated attenuation time series to compute statistics

Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

Description of the propagation experiment

Space segment



Hispasat
AMAZONAS-3

Satellite name	Amazonas 3
Orbit type	GEO
Orbit position	61°W
Frequency	20.1995 GHz
Polarization	RHCP
EIRP	≈ 20 dBW *

* Estimated from ONERA link budget and Rx dynamic range

Description of the propagation experiment

Installation site: French Guiana Space Centre in Kourou

Location	Latitude (°N)	Longitude (°E)	Altitude (km)	Elevation (°)	Azimuth (°)
CSG Kourou	5.1713	-52.6862	0.013	78.49	238.36

Description of the propagation experiment

Ground segment

- Ka-Band beacon receiver (2017-2020)
- Tipping bucket rain gauge (2017-2020)
- Tersus GNSS receiver (2018-2020)

Partnerships and schedule

- Partnerships

- Schedule

Equipments installation	December, 2016
Beginning of measurements	January, 2017
End of measurements	December 2020

Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

Data processing
Overview

Beacon receiver

Raw data (receiver power time series) → Beacon processing → Processed data (in-excess attenuation time series)

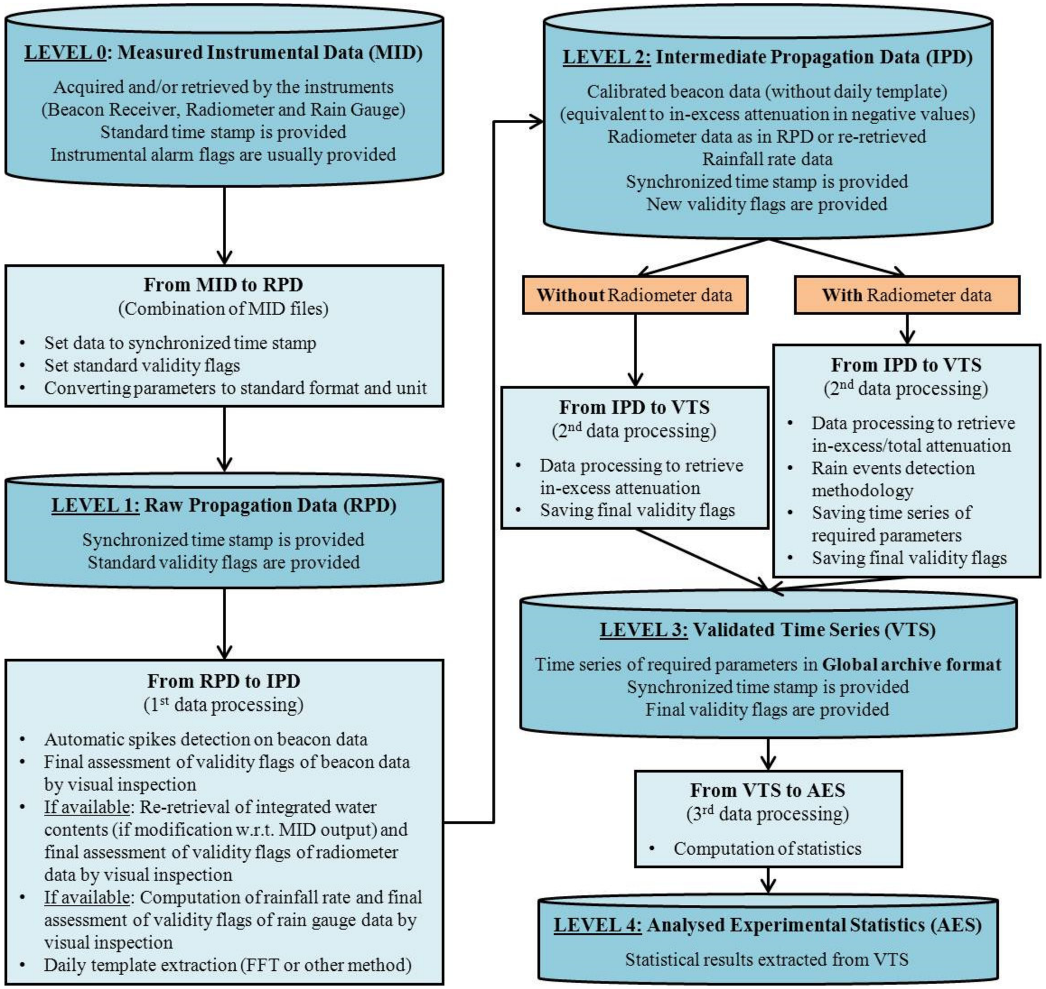
Rain gauge

Raw data (tips) → Rain gauge processing → Processed data (rain rates time series)

GNSS receiver

Raw data (GNSS observation & navigation files) → GNSS receiver processing → Processed data (IWVC)

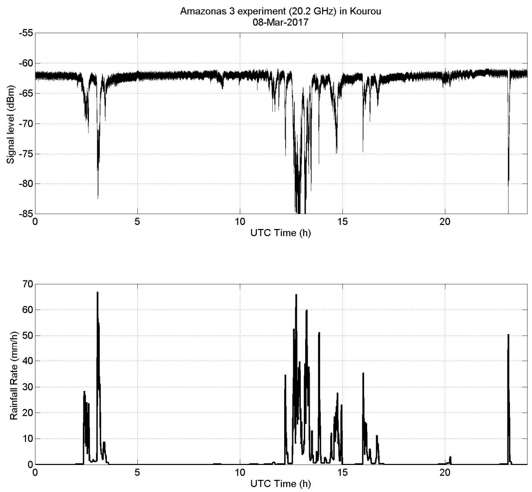
Data processing
Processing overview



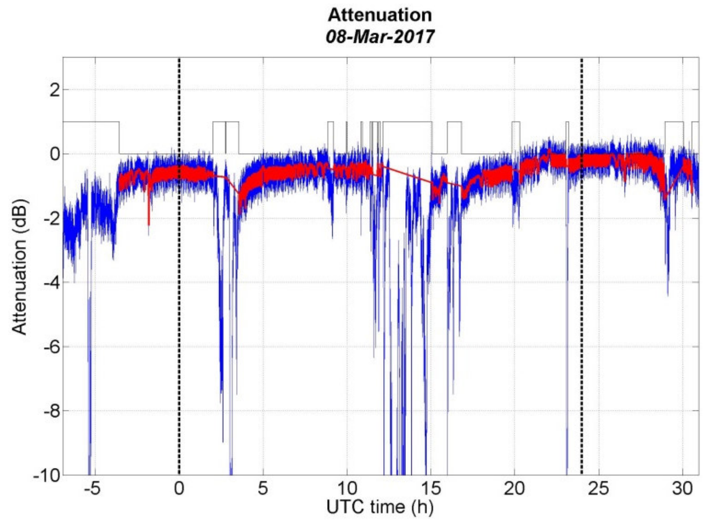
Data Format	Description
LEVEL 0: Measured Instrumental Data (MID)	Raw data acquired and/or retrieved by the measuring instruments (Beacon Receiver, Radiometer and Rain Gauge) often in several files. Instruments usually provide a time stamp, an alarm flag and data in private format.
LEVEL 1: Raw Propagation Data (RPD)	**Output of the combination of MID files** Data are referenced to synchronized time stamp and standard format for data and validity flag values (by assignment or conversion of MID data / time stamp / alarm flag). Measurements are grouped in a daily files.
LEVEL 2: Intermediate Propagation data (IPD)	**Output of the 1st data processing phase** Spikes in beacon data are automatically detected The daily template is computed. Integrated water contents are re-retrieved if modified. Rainfall rate is computed. A final validity assessment is performed by crossing measurements from various instruments and by user input.
LEVEL 3: Validated Time Series (VTS)	**Output of the 2nd data processing phase** Required propagation parameters time series are selected and provided, referenced to synchronized time stamp and final validity flag values. Data are saved in Global Archive format.
LEVEL 4: Analysed Experimental Statistics (AES)	**Output of the 3rd data processing phase** Statistical distributions of the propagation parameters are calculated from VTS.

Data processing
Beacon processing

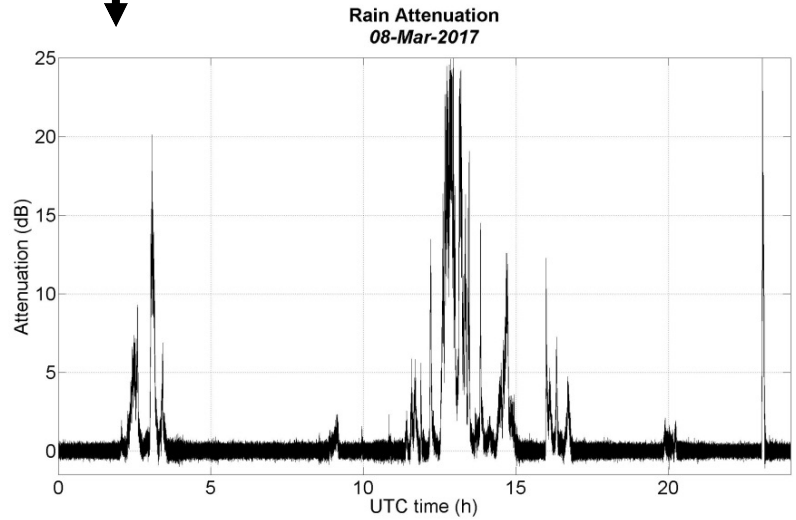
Raw Propagation Data (L0-L1)



Intermediate Propagation Data (L2)



Validated Time Series (L3)



1. Automatic pre-processing procedures (outliers removal, rough reference level)
2. Identification of rain events based on concurrent rainfall rate data (high correlation due to high elevation angle: ≈ 80º)
3. The beginning and the end of each rain attenuation event are manually adjusted

Data processing
GNSS receiver processing

rinex → CSRS → *ztd*

location → SYNOP → *zhd*

zwd = ztd - zhd

[1]

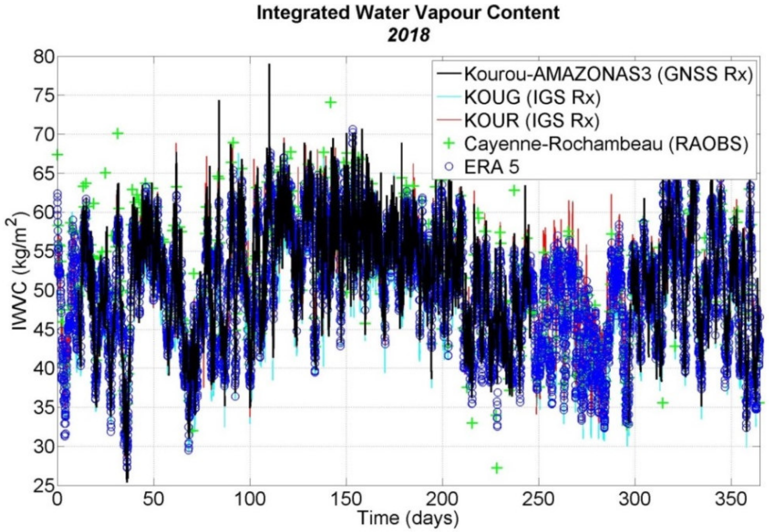
$$\Pi = \frac{10^6 M_w}{\rho\, R \left(k_2 - k_1 \frac{M_w}{M_d} + \frac{k_3}{T_m}\right)}$$

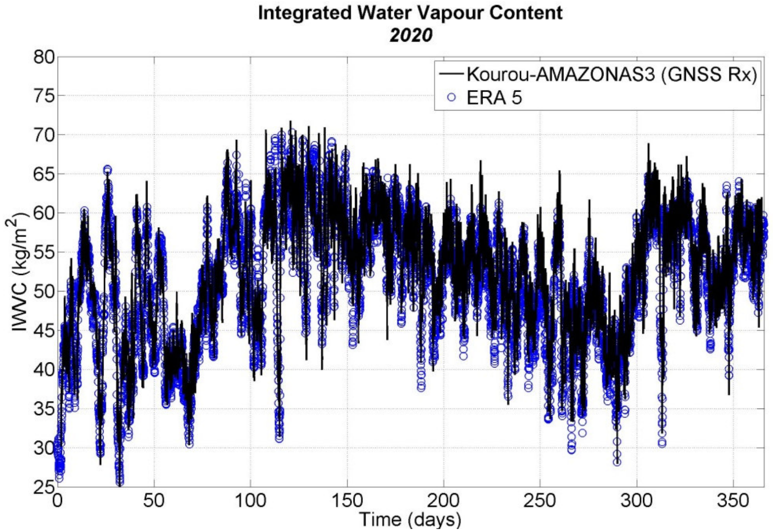
$$IWVC = \Pi \cdot zwd$$

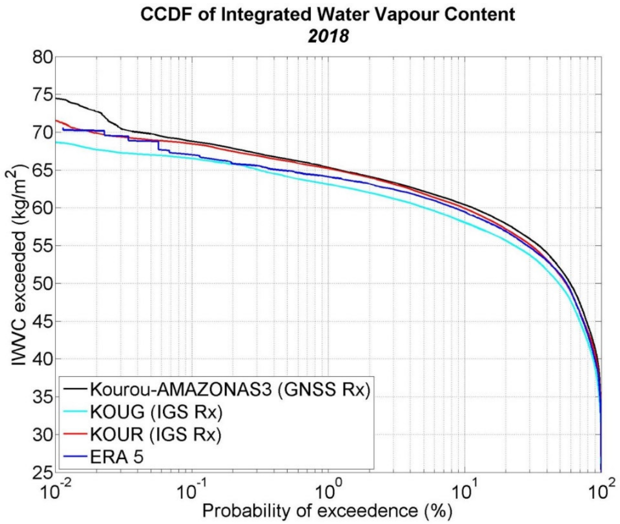
IWVC → ITU-R P.676-12 (Annex 2) → *Water vapour attenuation*

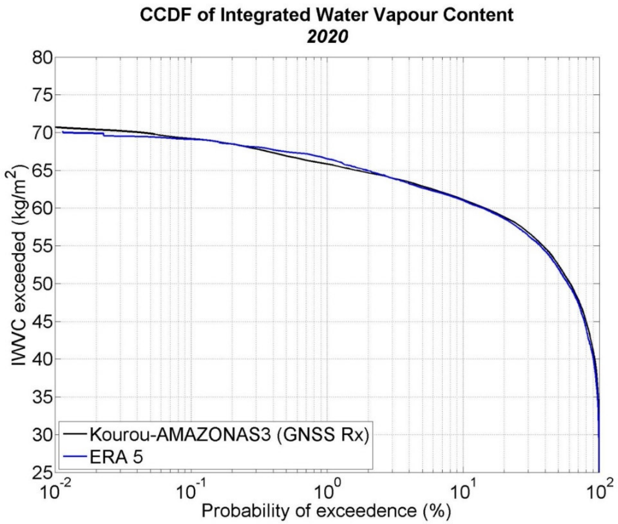
[1]	Bevis, et al, « GPS Meteorology' Remote Sensing of Atmospheric Water Vapor Using the Global Positioning System », JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. D14, PAGES 15,787-15,801, OCTOBER 20, 1992.
CSRS	PPP service hosted by Canadian government (https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en)
SYNOP	Surface meterological data provided by Météo France public service (https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=91&id_rubrique=32)

GNSS receiver based IWVC
IWVC time series and statistics









Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

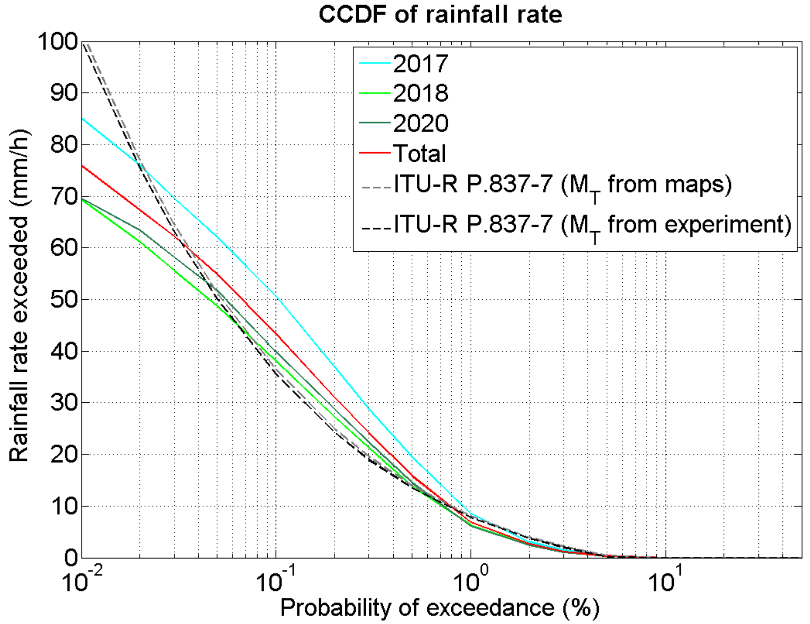
Statistical analysis and results

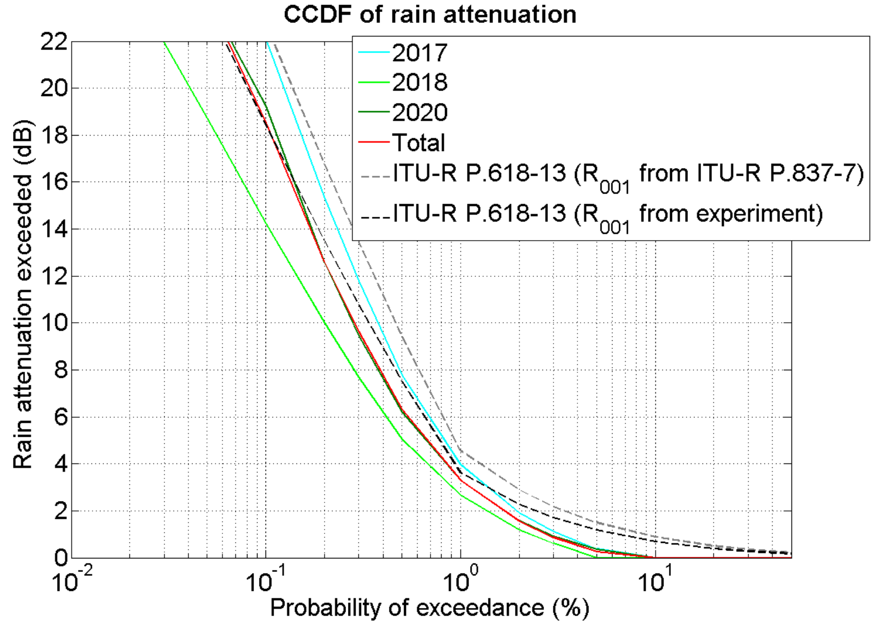
Data availability

	2017	2018	2020
Beacon receiver	99.65	99.73	99.41
Rain gauge	99.75	100	99.50
GNSS receiver		80.01	96.22

Annual valid propagation data (%) by equipment

Statistical analysis and results
Annual statistics of rainfall rate and rain attenuation





Inter-annual variability:

	2017	2018	2020
1 %	8 mm/h	6 mm/h	5 mm/h
0.5 %	20 mm/h	14 mm/h	15 mm/h
0.1 %	50 mm/h	38 mm/h	40 mm/h

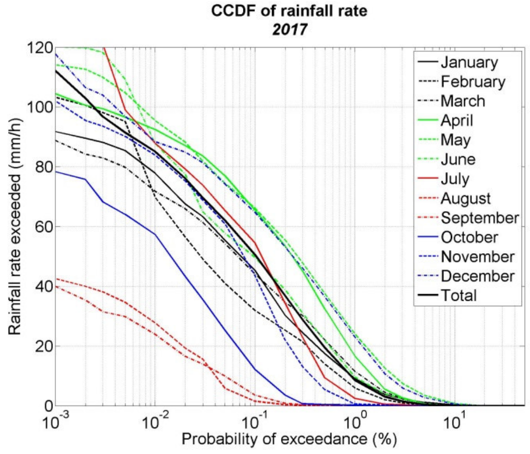
P.837-7 : annual M_T maps close to experimental values, but log-normal distribution not suitable in tropical-equatorial region

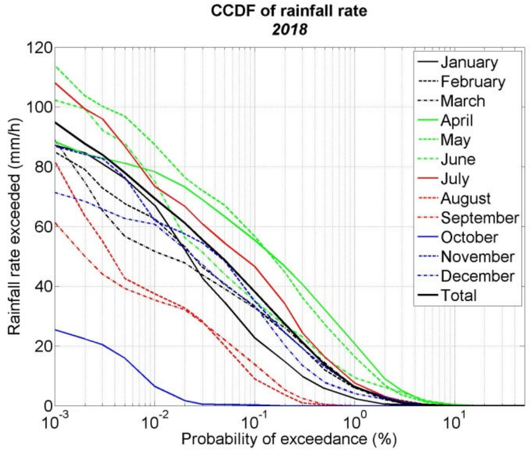
Inter-annual variability:

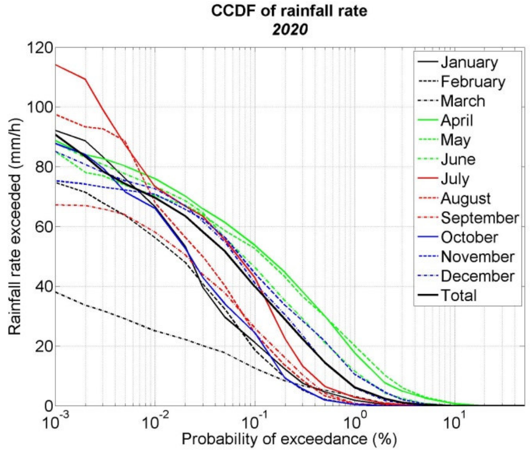
	2017	2018	2020
1 %	4 dB	2.3 dB	2.6 dB
0.5 %	7.5 dB	5 dB	6 dB
0.1 %	22 dB	14 dB	19 dB

Better prediction using exp R_{001} vs modelled R_{001}
Biais for p > 1%
In-excess attenuation: total attenuation would need clear-sky attenuation

Statistical analysis and results
Monthly statistics of rainfall rate



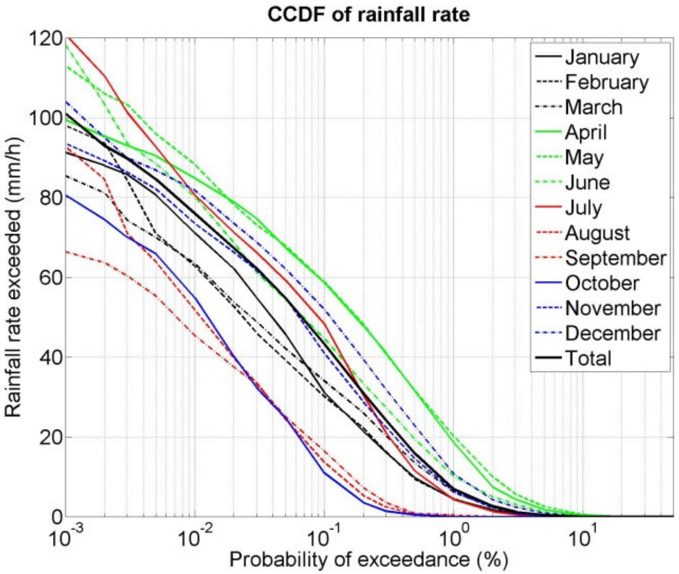




High seasonal variability due to seasonal climate characteristics

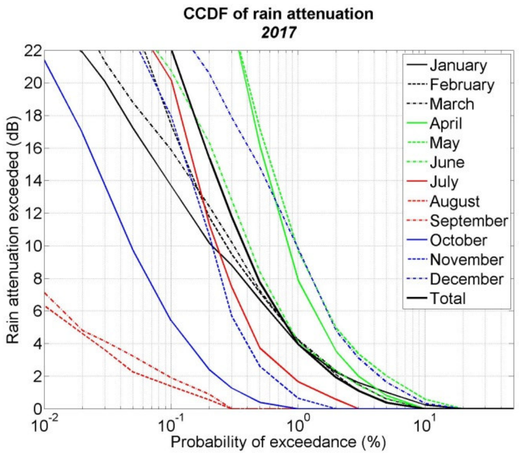
More years of data → more reliable mean CCDF

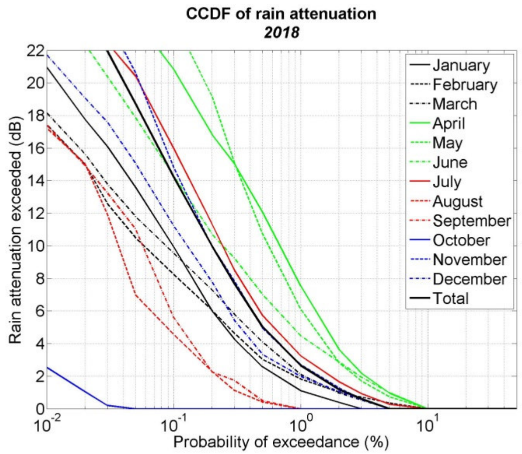
Need to keep collecting data in long term in order to compute reliable statistics vs seasonal variability

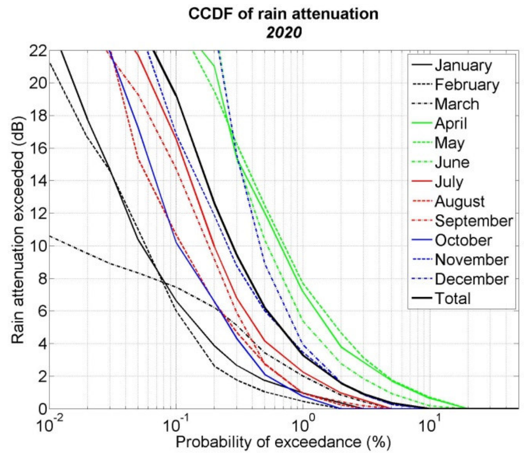


Statistical analysis and results

Monthly statistics of rain attenuation



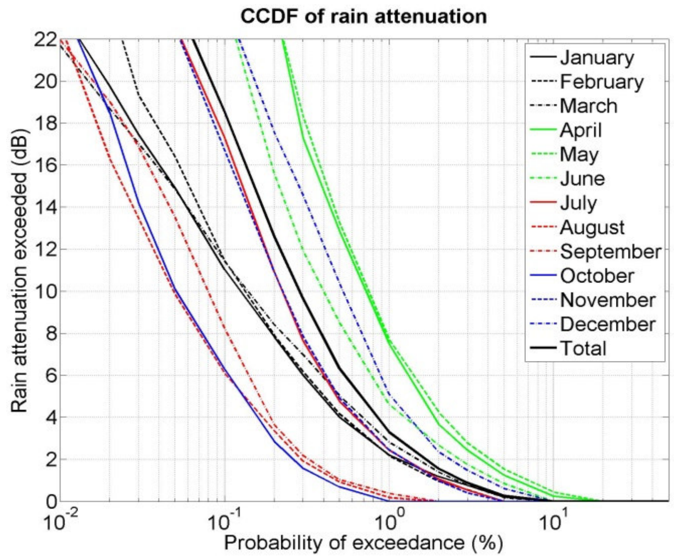




Very High seasonal variability due to seasonal climate characteristics

More years of data → more reliable mean CCDF

Need to keep collecting data in long term in order to compute reliable statistics vs seasonal variability

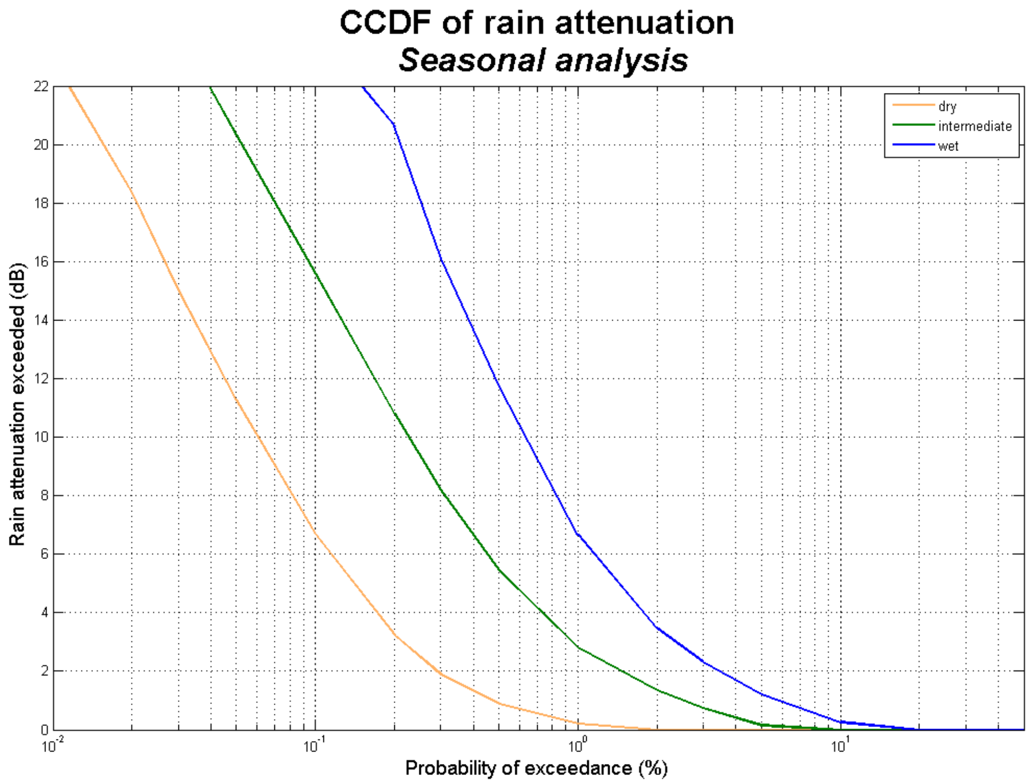


Statistical analysis and results
Seasonal analysis

Dry:
- August
- September
- October

Inter:
- January
- February
- March
- July
- November
- December

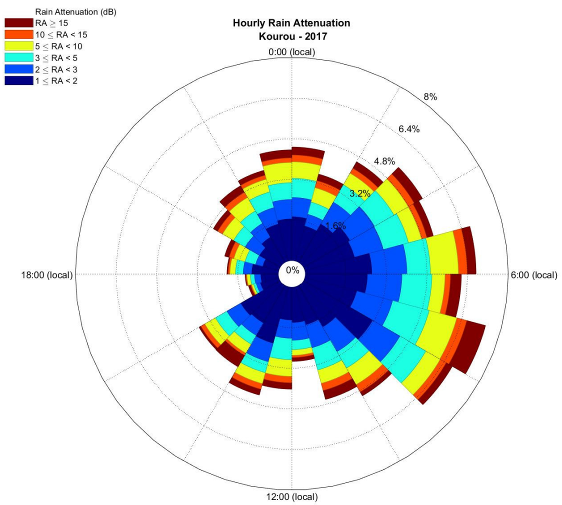
Wet:
- April
- May
- June

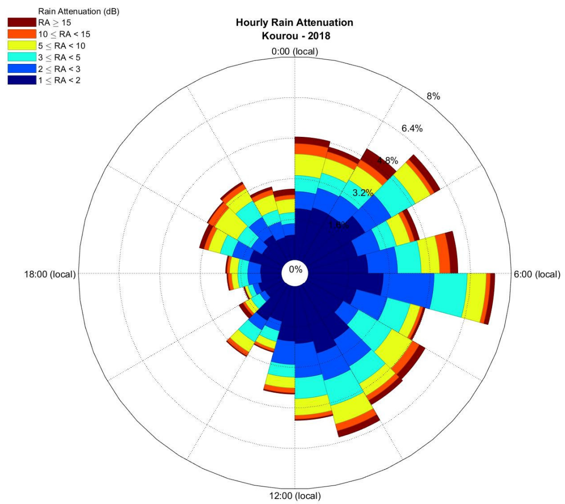


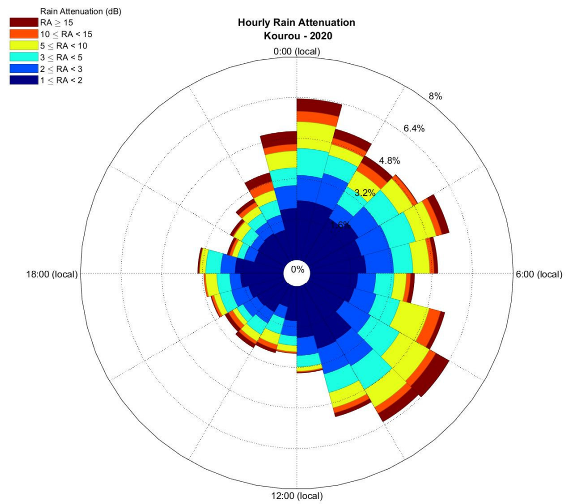
	dry	inter.	wet
1 %	0.3 dB	3 dB	7 dB
0.5 %	1 dB	5.5 dB	11 dB
0.1 %	7 dB	15.5 dB	>22 dB

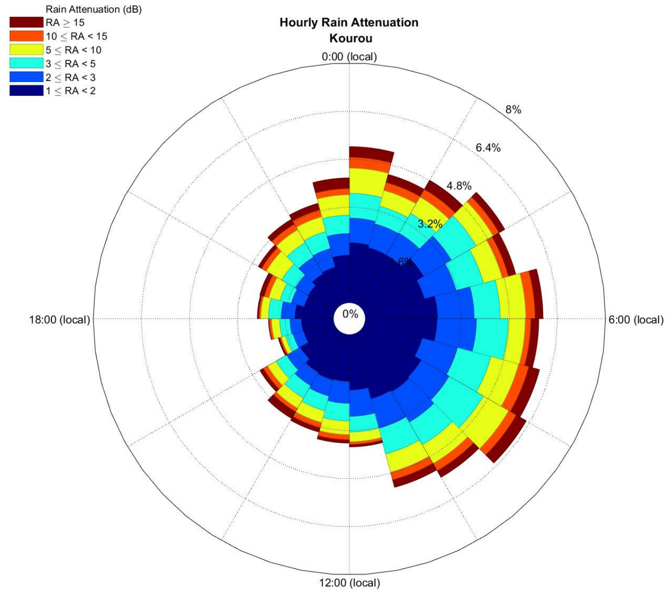
Statistical analysis and results

Hourly statistics of rate attenuation









Rain attenuation concentrated around from 0h to 12h local time

Inter-annual variability

Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

Conclusion and perspectives

3 years of processed rainfall rates and rain attenuation data in equatorial area with excellent availability (one of the best in the World in 2017-18-20)

Variability of the propagation channel

- Annual, seasonal, monthly and hourly analyses available
  - 2017 very rainy, especially in January and December
  - 2020 very dry from January to mars
- 8 dB difference between the most favourable year and the worst year at 0.1 %
- 20 dB difference between the most favourable month and the worst month at 0.2 %

Comparisons with prediction methods in Recommendations ITU-R P.837-7 (rainfall rate) and ITU-R P.618-13 (rain attenuation)

- Significant differences wrt. ITU-R P.837-7 for probability of exceedance < 10^{-2} %
- Good results wrt. ITU-R P.618-13 for % below 1% but poor results above

2 years of IWVC data in equatorial area with excellent availability

- GNSS receiver based inversion procedure validated wrt. ERA5 reanalysis database

Conclusion and perspectives

Strong inter-annual and inter-month variabilities (in a 3 years long experiment only) that strongly suggest to extend the collection data to derive reliable CCDFs

Need support to extend propagation experiment

Improvement of the dynamic range of the measurements in order to improve the statistical analyses (e.g. by the use the E65WA Ka-band beacon and by replacing the beacon receiver by an SDR-based ones)

Add ancillary equipments to the ground segment to collect other meteorological data (radiometer, micro-rain radar, disdrometer, etc.)

Set up a diversity experiment in tropical area using other sites in French Guiana (two sites under investigation: Cayenne airport and Montagne des Pères)

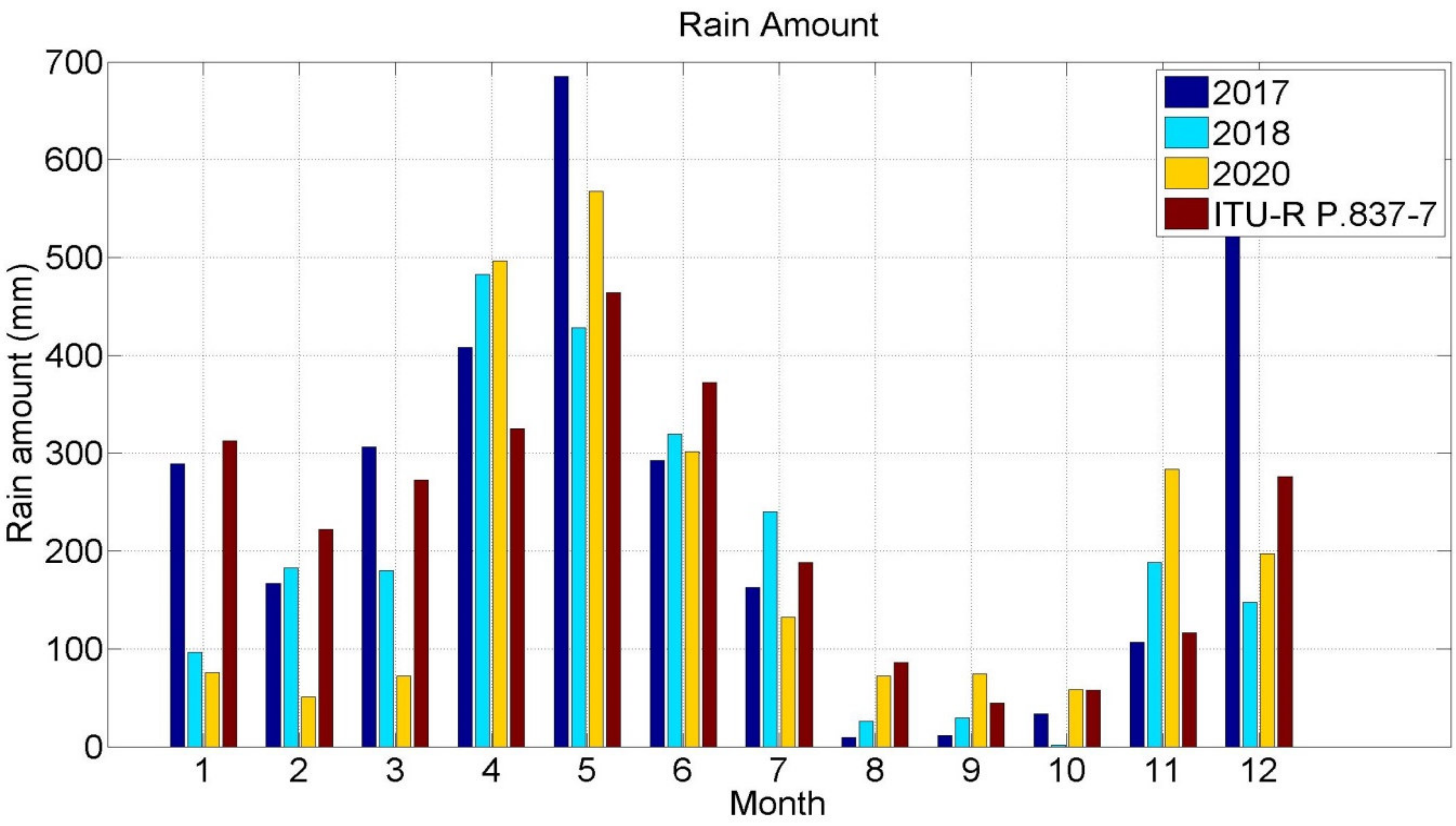
Kourou vs other sites in French Guiana

Outline

- Context of the study
- Description of the propagation experiment
- Data processing
- Statistical analysis and results
- Conclusion and perspectives
- Discussion

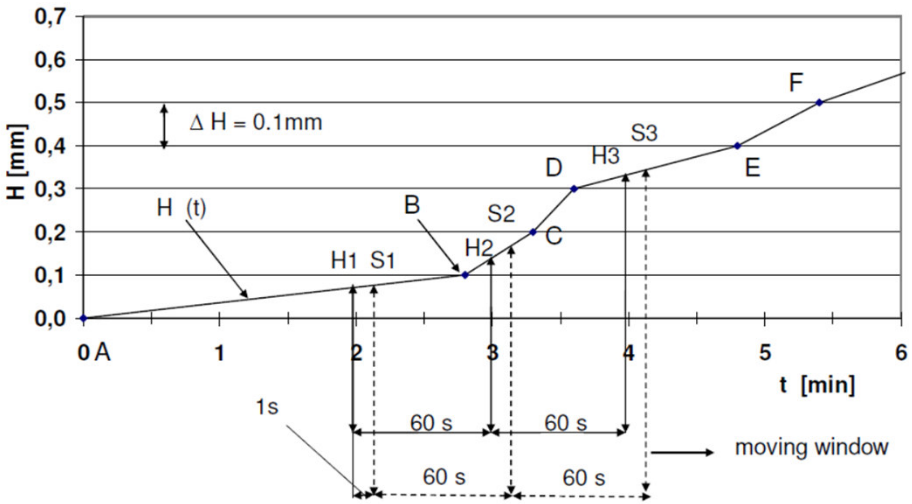
Appendices

Statistical analysis and results
Rain amount



Data processing
Rain gauge processing

Tips → IAP recommended method (Sliding window derivative of accumulated rain amount) → **RR**



IAP Institute of Atmospheric Physics

Statistical analysis and results

Inter-annual variability of monthly statistics of rain attenuation