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Validation of rainfall estimation derived from commercial DVB received signal with disdrometer, rain gauges and ground based radar

Adirosi, E.[1], Baldini, L.[1], Facheris, L.[2], Giannetti F.[3], Antonini, A.[4], Melani, S.[4,5], Vaccaro, A.[6], Petrolino, A.[6]

[1] Institute of Atmospheric Sciences and Climate, CNR, Rome, Italy; [2] Dipartimento di Elettronica e Telecomunicazioni, Università di Firenze, Florence, Italy; [3] Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Pisa, Italy; [4] LaMMA Consortium, Sesto Fiorentino (FI), Italy; [5] Institute of Biometeorology, CNR, Sesto Fiorentino (FI), Italy; [6]MBI Srl, Pisa, Italy.

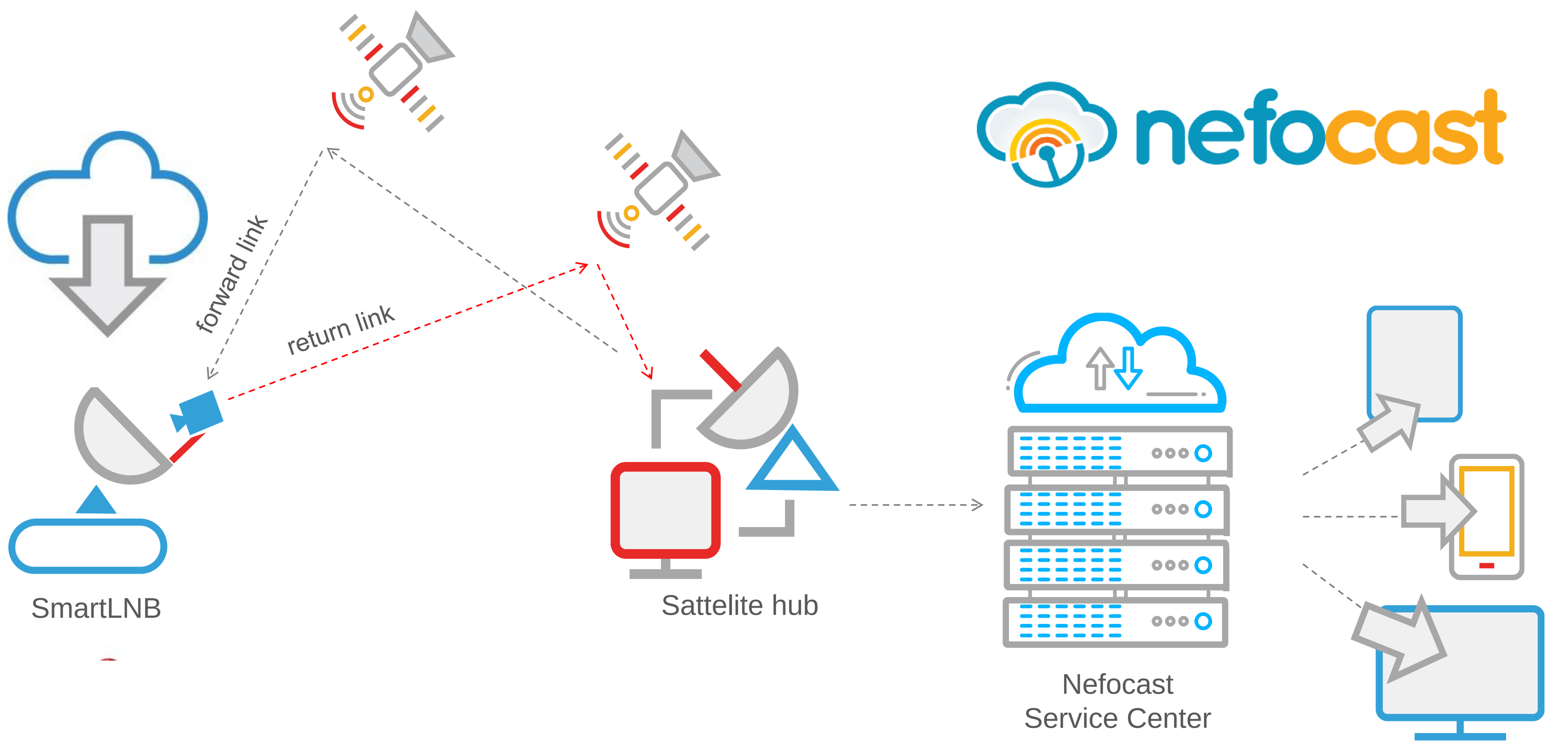
THE NEFOCAST PROJECT

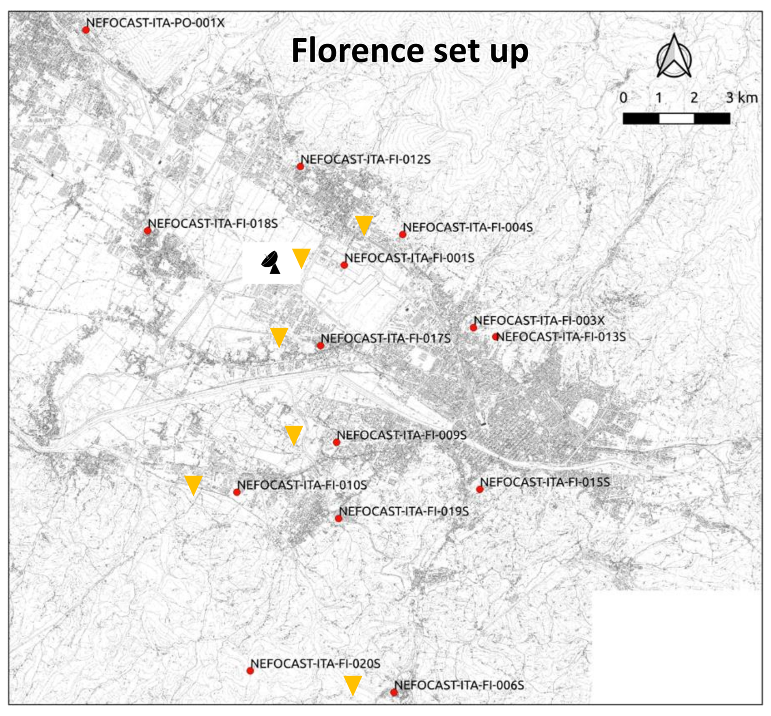
In the last decade, a new method that exploits microwave satellite links has been investigated to retrieve precipitation properties: the idea is to estimate the precipitation from the attenuation experienced by signals transmitted by telecommunication satellite link along their propagation path.

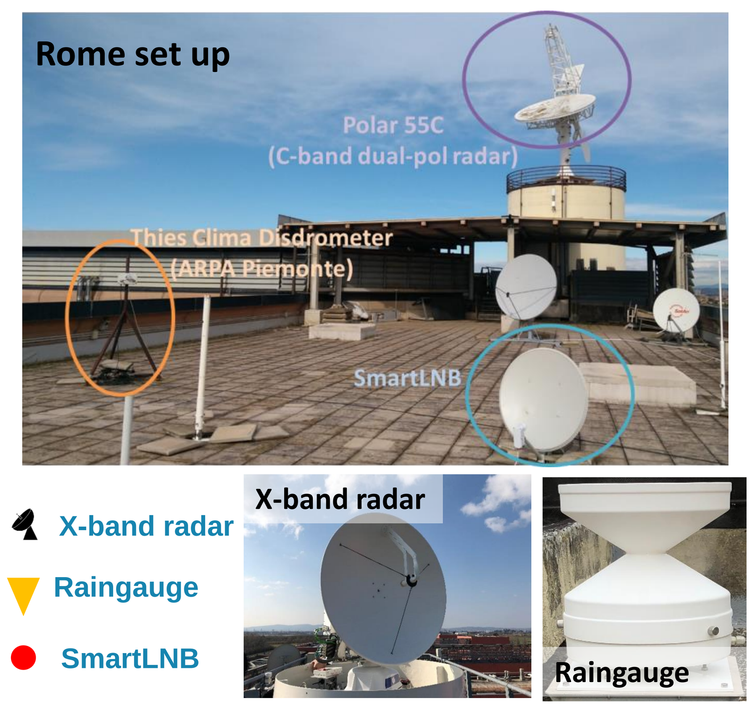
The project **NEFOCAST** funded by Tuscany Region (Italy) has been carried out with the aim of estimating rainfall rate starting from Ku-band attenuation measurements made available by commercial interactive digital video broadcasting (DVB-S2) receivers called SmartLNB (smart low-noise block converter) managed by Eutelsat.

The SmartLNB is an innovative two-way (*i.e.*, transmit/receive) device that can serves as weather sensor being able to collect attenuation data and make them available to a dedicated platform.

The main expected advantage in estimating precipitation with SmartLNBs is the potentially huge amount of data available worldwide at low cost (in terms of installation and maintenance) and at high spatial resolution with respect to the conventional meteorological devices.







THE NEFOCAST EXPERIMENTAL CAMPAIGN

One-year experimental campaign has been carried out in Italy to tune, test and validate the NEFOCAST precipitation retrieval algorithm.

A network of 24 SmartLNBs has been installed in Tuscany (Italy) and a dedicated platform, the NEFOCAST Service Center (NSC), has been set up where data are collected via ground-to-satellite link, processed and shared with value-added service providers (VASPs). Furthermore, a set of co-located rain-gauges has been deployed along with an X-band dual-pol radar (nominal frequency 9.41 GHz) covering the whole test area. In Florence there are 6 sites with SmartLNB and co-located raingauge.

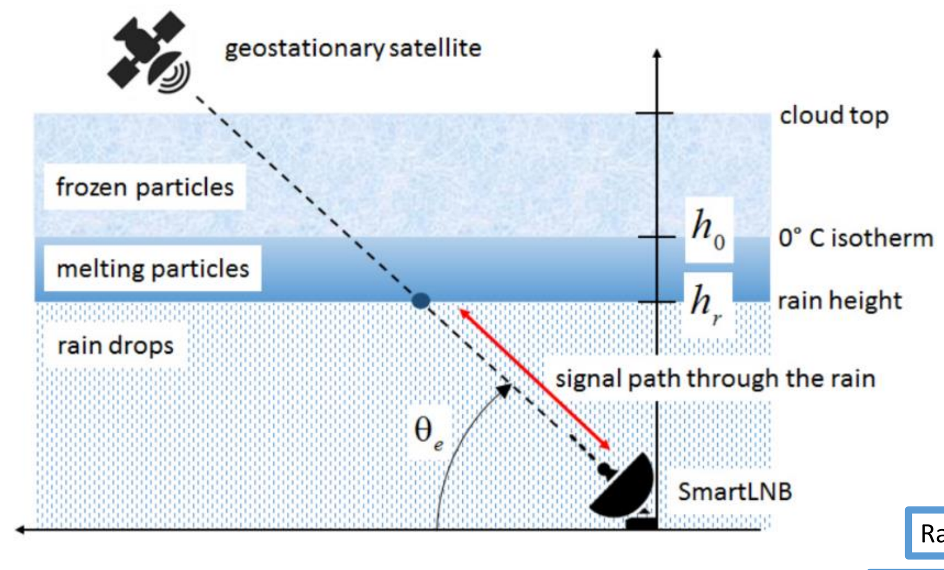
A SmartLNB has been installed also on the roof of the Institute of Atmospheric Sciences and Climate (ISAC) of the CNR in Rome in order to exploit the synergy with the disdrometer and the C-band weather radar (Polar 55C) available on site.

THE NEFOCAST RAIN RATE RETRIEVAL ALGORITHM

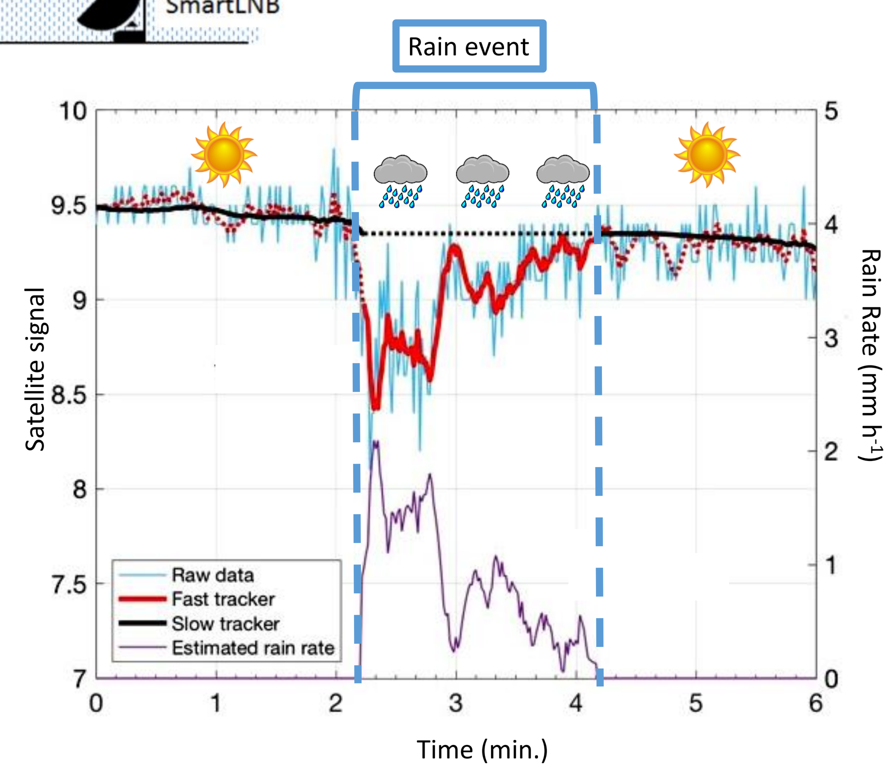
SmartLNBs measure the signal-to-noise ratio ($\eta = E_s/N_0$). The presence of precipitation in liquid or mixing phase along the Earth-space link causes an attenuation of the signal that depend on the precipitation intensity. However, E_s/N_0 in clear sky is not constant but varies due to tropospheric scintillations and changes in the satellite position. To obtain a reliable E_s/N_0 value to be used as reference to compute the attenuation due to precipitation, a double Kalman filter has been adopted. Knowing the E_s/N_0, the attenuation due to precipitation (L_{rain} in dB) along the path can be estimated. Neglecting the contribution of ice particle, L_{rain} is the sum of the contribution due to liquid drops in the liquid layer (LL) and the one due to particles within the Melting Layer (ML):

$$L_{rain}(t) = \alpha_{ML}[R]^{\beta_{ML}} \left[\frac{\delta_{ML}}{(\beta_{ML}+1)\, sen(\vartheta)}\right] + \alpha_{LL}[R]^{\beta_{LL}} \left[\frac{h_0-\delta_{ML}}{sen(\vartheta)}\right]$$

Coefficients α_{ML} and β_{ML} were obtained from Dissanayake et al. (1997, *IEEE Trans. Antennas Propag.*), while α_{LL} and β_{LL} were obtained experimentally from a long time series of disdrometer measured Drop Size Distribution (DSD) in Rome (Giannetti et al. 2017, *Sensors*). The height of the 0°C isotherm (h_0) is the output of the numerical weather prediction model run by LAMMA consortium, while the thickness of the ML (δ_{ML}) has been set constant and equal to 500 m. Knowing L_{rain}, from the latter equation, it is possible to retrieve the rainfall rate (R) with a step of 1 minute.



Geometry of an Earth-space radio link in stratiform precipitation.

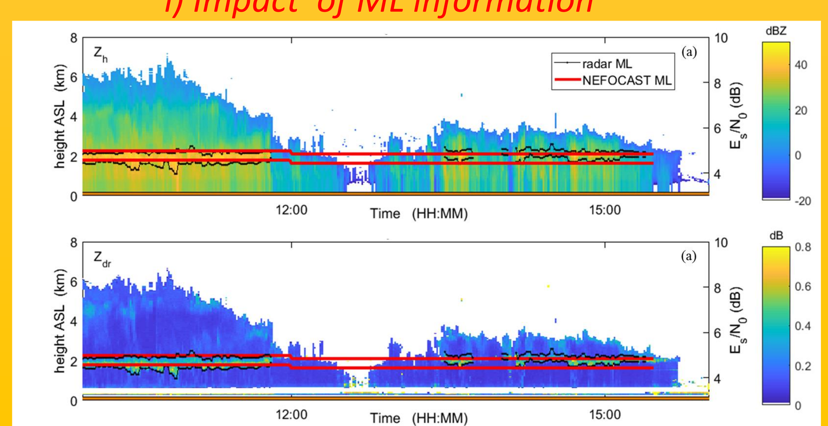


Example of SmartLNB data and retrieval during a precipitation event occurred in Pisa (Tuscany, Italy).

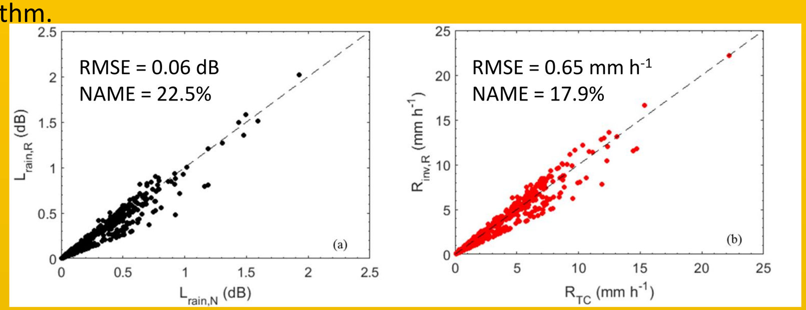
EVALUATION OF THE NEFOCAST RAIN RETRIEVAL ALGORITHM

Thanks to the use of disdrometer and Polar55C radar data at ISAC-CNR in Rome we were able to quantify the effects on the rain retrieval of *i)* error in estimating of h_0 and δ_{ML} and *ii)* error in the coefficient α_{LL} and β_{LL} to convert the specific attenuation *k* in rain rate.

i) Impact of ML information



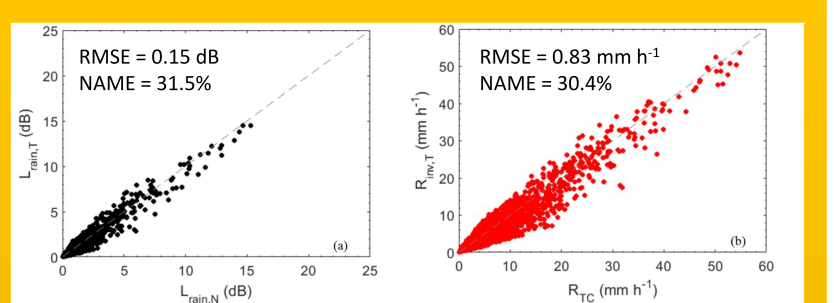
Example: Time series of (a) Z_h and Z_{dr} collected by Polar 55C on 8 April 2018. Superimposed black lines represent the bottom and top of ML as obtained from radar data applying the Baldini and Gorgucci (2006; JTECH) algorithm, while red lines represents the bottom and top of ML used in the NEFOCAST algorithm.



ii) Impact of R-k relation

In this analysis. the disdrometer data available in Rome have been used.

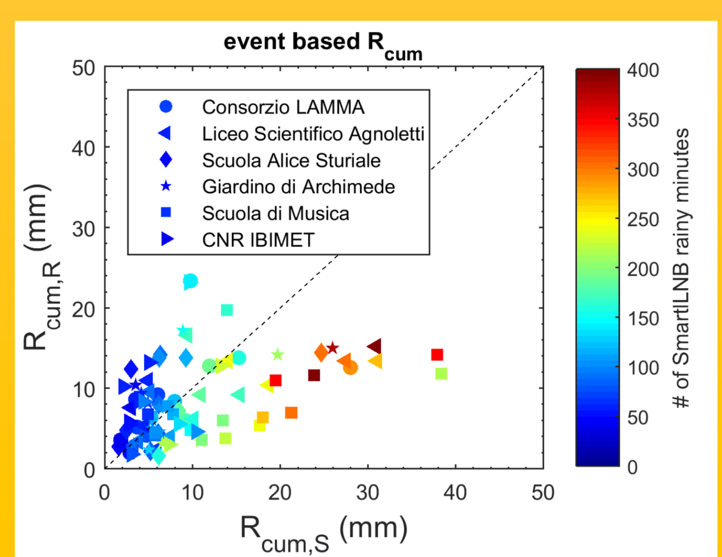
The disdrometer estimates the drop size distribution (DSD): for each DSD it is then possible to obtain the specific attenuation and the path integrated attenuation due to rain ($L_{rain,T}$) through the T-matrix electromagnetic simulation model.



- R_{TC} = rain rate obtained directly from disdrometer-derived DSD
- $L_{rain,N}$ = attenuation computed using R_{TC} and h_0 and δ_{ML} used in the NEFOCAST algorithm
- $L_{rain,R}$ = attenuation computed using R_{TC} and h_0 and δ_{ML} obtained from Polar55C data
- $L_{rain,T}$ = attenuation computed from disdrometer-derived DSD and T-matrix simulation
- $R_{inv,R}$ = rain rate computed using $L_{rain,R}$ and h_0 and δ_{ML} used in the NEFOCAST algorithm
- $R_{inv,T}$ = rain rate computed using $L_{rain,T}$ and h_0 and δ_{ML} used in the NEFOCAST algorithm

EVALUATION OF THE PRECIPITATION ESTIMATION FROM SMARTLNB

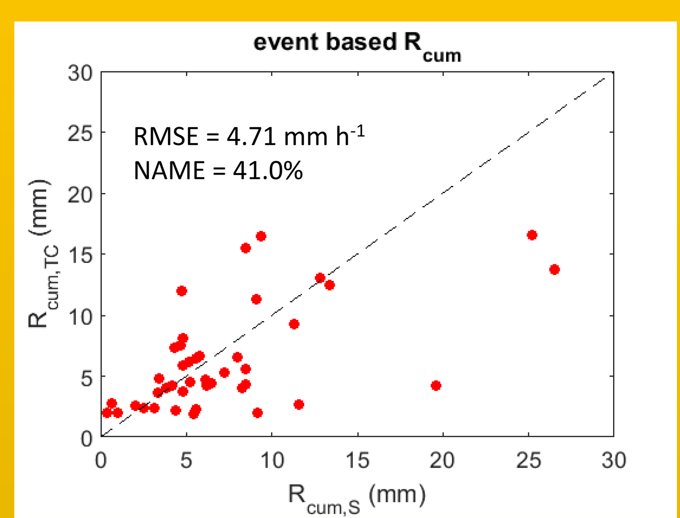
Florence Area: SmartLNB vs Raingauge



Scatterplot between event based cumulated precipitation obtained from SmartLNB (x-axis) and the co-located raingauge (y-axis). The colorbar represent the number of rainy minutes collected by SmartLNB within the event.

Site name	RMSE (mm)	NMAE (%)
Consorzio LAMMA	6.07	44.3
Liceo Scientifico Agnoletti	7.82	48.1
Scuola Alice Sturiale	5.61	64.6
Guardino di Archimede	5.25	49.7
Scuola di musica	11.54	56.0
CNR IBIMET	5.71	82.4
All sites	7.58	55.1

Rome: SmartLNB vs Disdrometer



Scatterplot between event-based cumulated precipitation obtained from SmartLNB (x-axis) and the co-located disdrometer (y-axis). The disdrometer provides a more accurate measurement of the instantaneous rainfall rate with respect to the raingauge.

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