An EnKF-based reconstruction of rainfall fields using opportunistic satellite MW link signal attenuation: theoretical basis and application to the July 2021 event in the area of Dortmund (Germany)

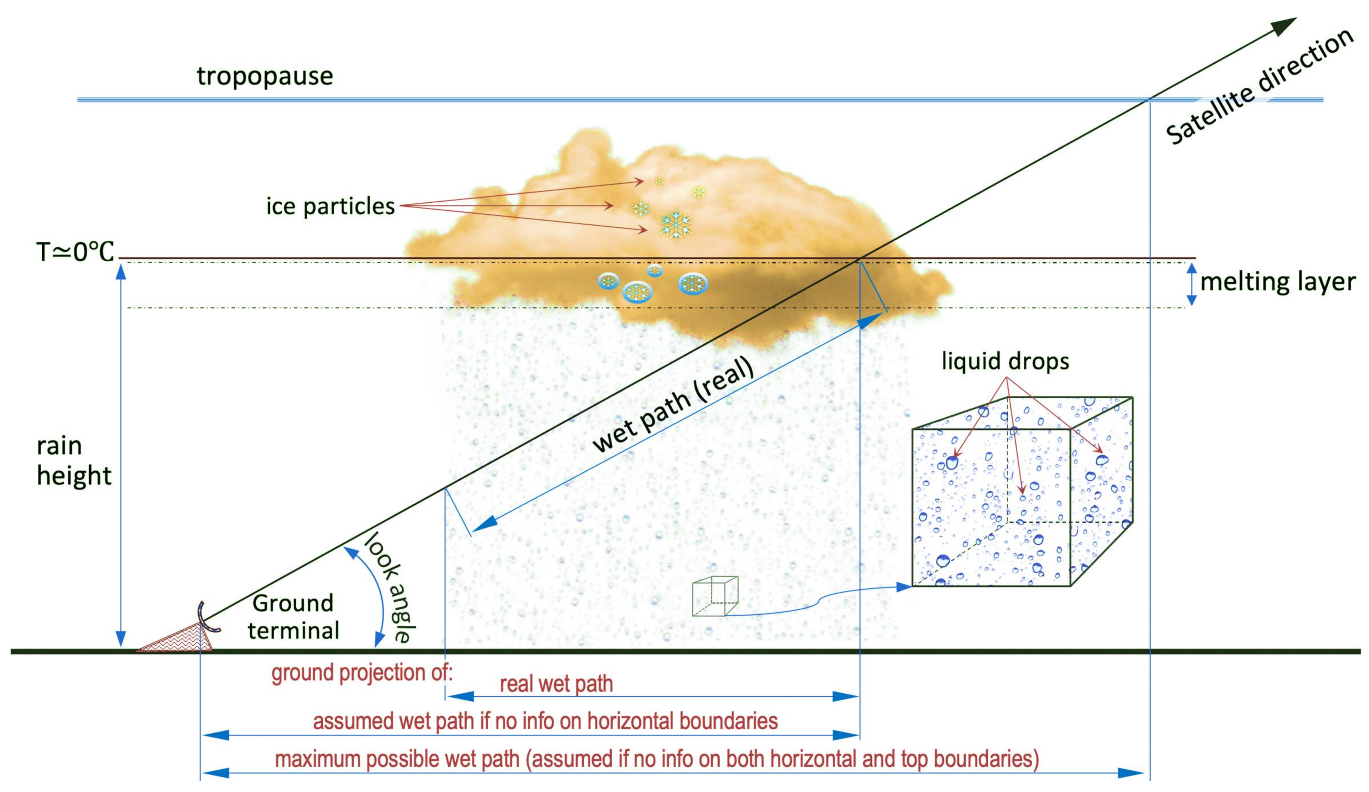
A: Ortolani[1,2], F. Caparrini[2], S. Melani[1,2], A. Antonini[2], A. Mazza[1,2], F. Giannetti[3], F. Sapienza[3], L. Facheris[4], L. Baldini[5], E. Adirosi[5], A. Vaccaro[6]

Contact: Alberto Ortolani ortolani@lamma.toscana.it

[1]CNR-IBE, Sesto Fiorentino (Florence), Italy
[2]Consorzio LaMMA, Sesto Fiorentino (Florence), Italy
[3]Università di Pisa, Pisa, Italy
[4]Università degli studi di Firenze, Florence, Italy
[5]CNR-ISAC, Rome, Italy
[6]M.B.I. S.r.l., Pisa, Italy

Rationale and measurement concept

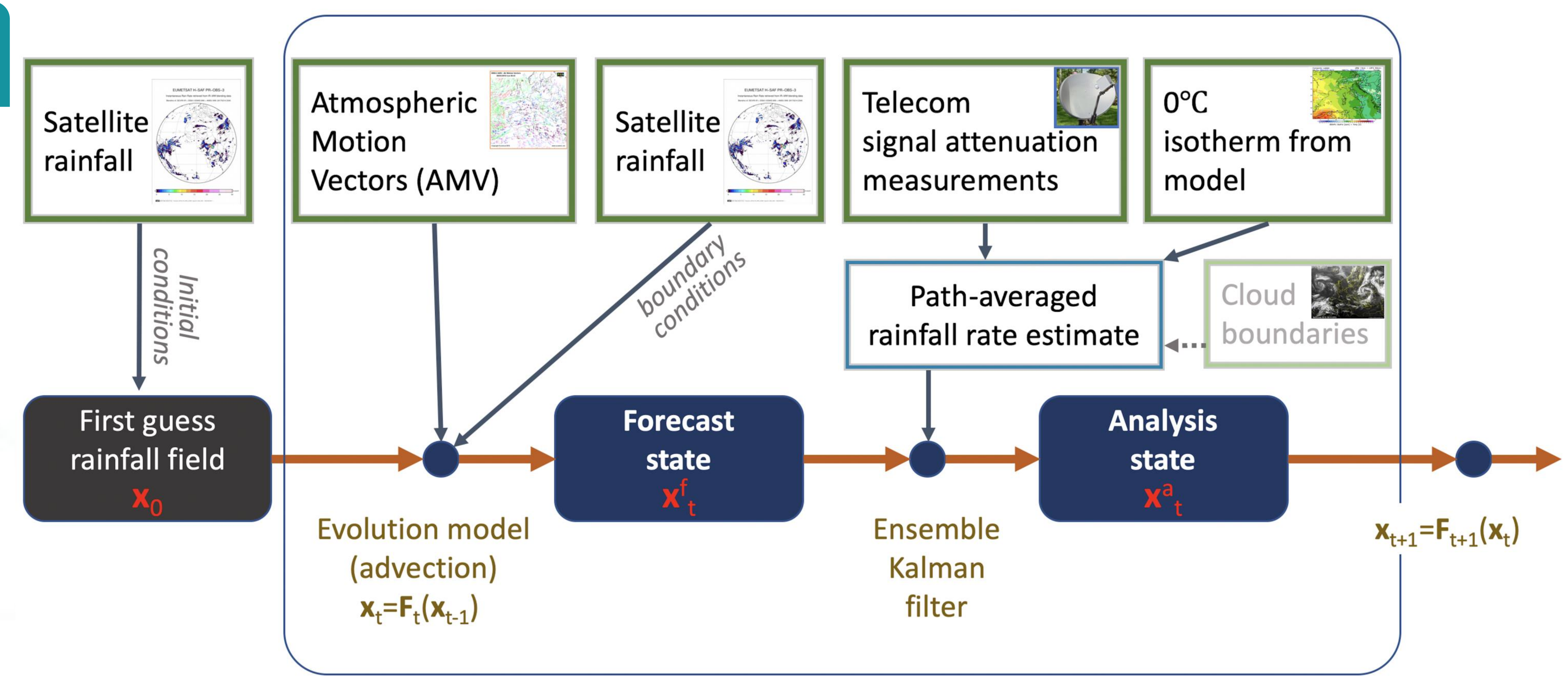
Estimates of rainfall fields is critical for several scientific and operational applications, but they are difficult due to rainfall temporal and spatial variability. Moreover, rainfall regimes are changing with a complex connection to the climate change. Measurements of opportunity can help to reduce exiting information gaps for estimating of rainfall fields . Microwave (MW) broadcast telecommunication satellite signals can be used at the purpose, as raindrops attenuate the signal along the propagation path. Here we use data from Smart Low-Noise Block converter (Smart-LNB) pointing to a Eutelsat telecommunication geostationary satellite, with ancillary information to constraint the top boundary of the rainfall system.

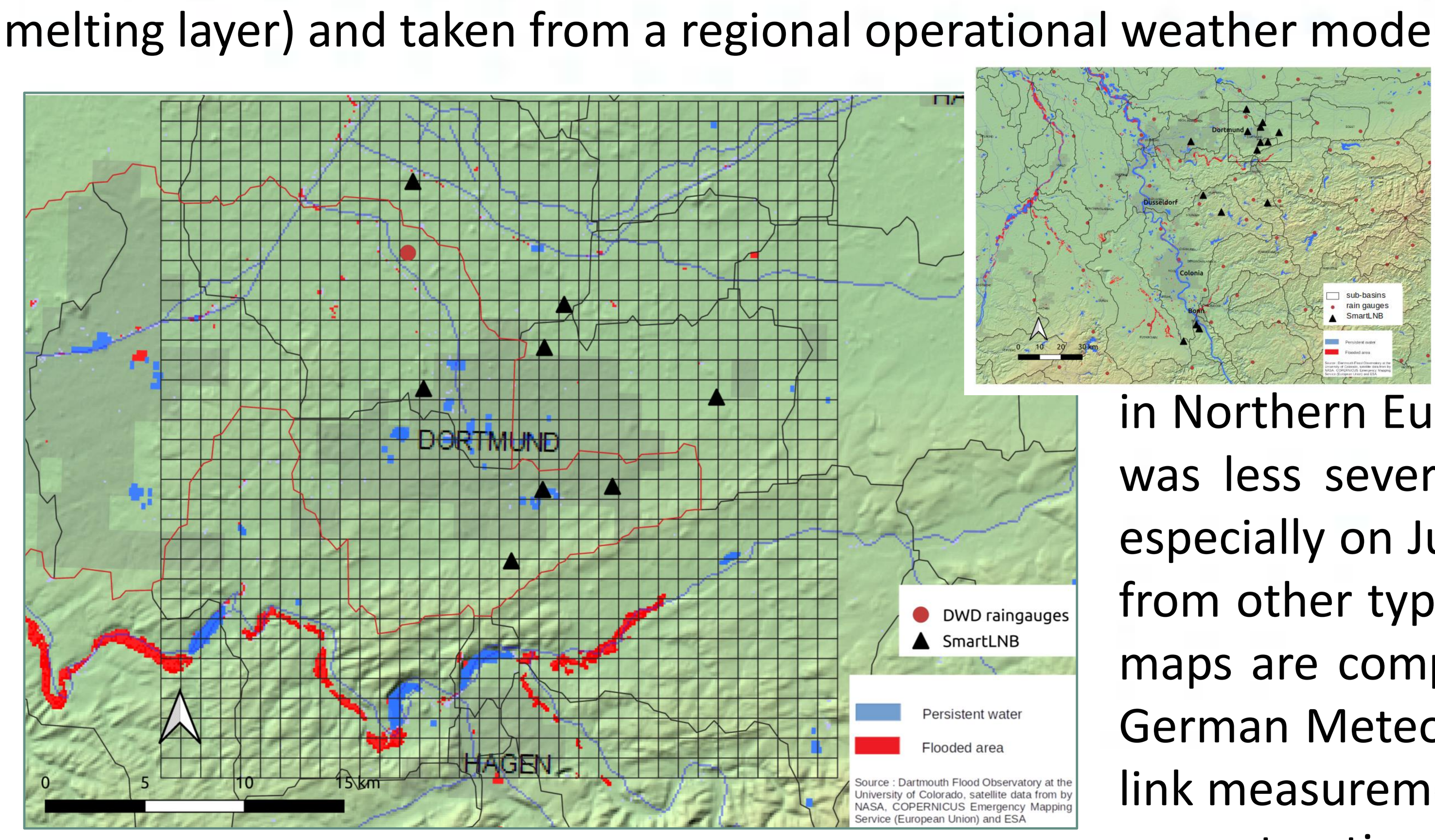


The specific MW signal attenuation k (dB/km) is related to the instantaneous rain rate R (mm/h), by a power-law in the form $k=a{\cdot}R^b$, where a and b are coefficients that depend on the carrier frequency (typically 10–40 GHz) and on the polarization, and rainfall characteristics. Any geostationary satellites is connected with a set of ground receiving terminals (GTs) via a slanted path which intercepts precipitation. Each GT yields estimates of the received signal-to-noise ratio, at one sample per minute (or even at higher rates). The start of a rain event produces a sudden drop of the Signal-to-noise ratio (SNR) value which is detected by the retrieval algorithm. Then the rain-induced SNR loss is evaluated by comparing the current "wet" SNR reading with a reference level relevant to "dry" conditions. An innovative (patented) algorithm exploits the link geometry and a novel tropospheric model to derive the specific rain attenuation and, eventually, the associated rain rate. The precipitation ends when the observed "wet" SNR reaches the "dry" reference. Retrievals have been validate against raingauge, disdrometer and weather radar (Adirosi at al., 2020).

EnKF-based rainfall fields

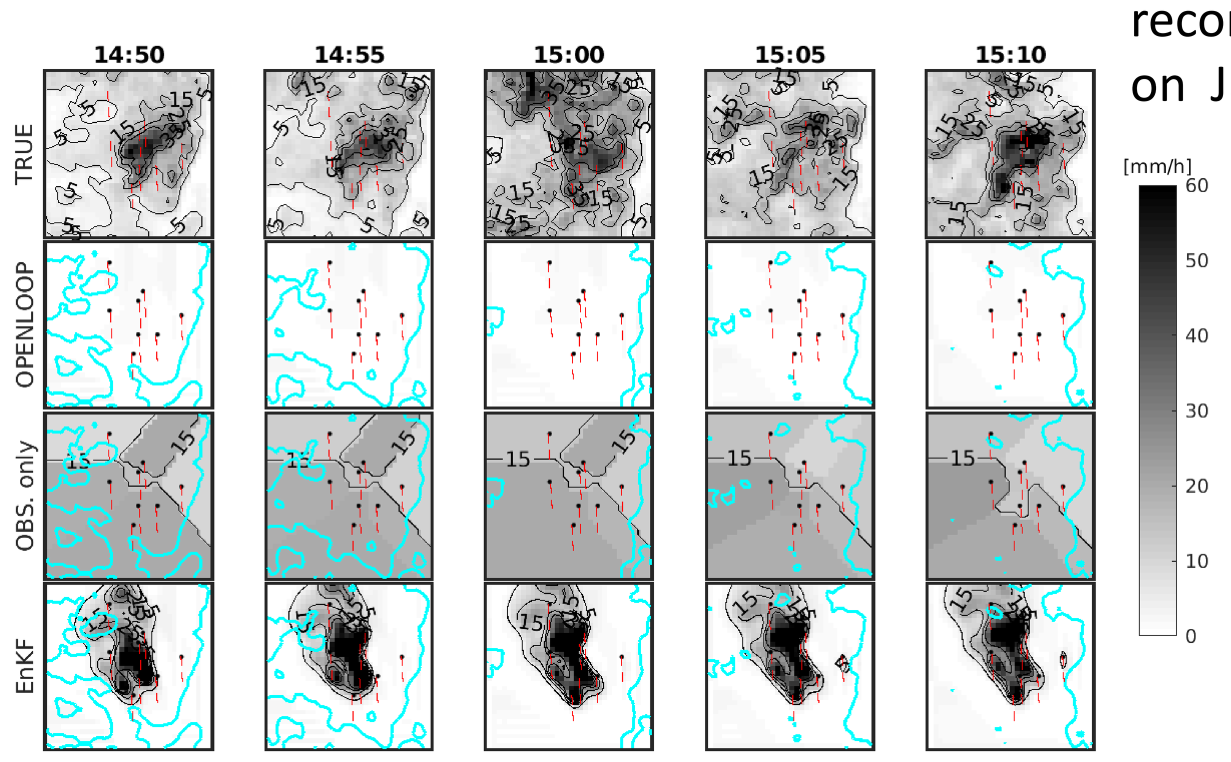
The high time rate of measurements and the potential high spatial density of the SmartLNBs suggests to approach the retrieval of bidimensional spatialised rainfall maps from along-path averaged rain rates, similarly to a trajectory assessment in a phase space, using an Ensemble Kalman Filter (EnKF) methodology (Ortolani et al., 2021). Actually measurements are processed using a spatio-temporal data assimilation framework based on an EnKF, that integrates observations with a simple storm advection model driven by Atmospheric Motion Vectors (AMV) from Meteosat Second Generation data. Boundary (and initial) conditions are from the MSG Instantaneous rain rate products. The 0°C isotherm atmospheric level is assumed as the precipitation top boundary (i.e. top of the melting layer) and taken from a regional operational weather model.





The Dortmund case study of mid July 2021

The EnKF methodology has been applied to obtain gridded rainfall fields at fine temporal (5 min.) and spatial (1 km) resolution, for the heavy rain event of July 13 and 14, 2021. The study area is the gridded one in the left figure, of about 1000 km^2 (35x35 km) surrounding the city of Dortmund (North Rhine-Westphalia, upper basin of Ermscher river). The event was one of the most relevant in Northern Europe in the last years, causing floods, with fatalities and great damages. Although the Dortmund area was less severely hit compared to other areas in North Rhine-Westphalia, it was interested by intense rainfall especially on July 14. Only one operational rain gauge is accessible for the area, so the availability of measurements from other types of sensors may be very useful to retrieve spatial patterns and localized phenomena. The resulting maps are compared with those provided from RADOLAN (radar based quantitative precipitation products) by the German Meteorological Service. The comparison (bottom-left figure) shows the potential benefit of using the MW-link measurements to improve the ones from a sparse raingauge network, enabling a more detailed spatio-temporal reconstructions of the rainfall fields. Rainfall fields are at ground level at 5 min. time steps from 14:50 to 15:10 UTC on July 14, 2021. Estimated isothermal height during the event was 4 km. Dots indicate the locations of the SmartLNBs; red dashed lines their paths (projected at ground). The first row shows our reference (say "true") rain rate [mm/h] from RADOLAN 5 minutes product. The second row shows the rain rates obtained from the openloop model, which uses only advection velocities (AMVs on average point to N-NW) and first guess rain rate from EUMETSAT MSG satellite products (in this case providing unrealistic light rainfall). The third row instead shows the rainfall fields obtained interpolating the rain rate estimations from SmartLNBs, with simple nearest neighbour interpolation. Finally, the fourth row shows EnKF rainfall fields, with N=100 ensembles, exploiting SmartLNB and satellite information. The cyan outline in rows 2,3,4 marks the boundaries of the true rainfall (i.e. from RADOLAN), in order to help the correct placement of the precipitation fields.



The new multi beam device

A brand new receiver is under testing, which is capable of measuring from several satellite signals, simultaneously received from multiple geostationary platforms, seen from different directions. This receiver makes use of standard broadcasting satellite transmissions in Ku band. A toroidal dual reflector antenna is used, capable of hosting up to 16 different Low Noise Block (LNB) converters, with a total angular separation of up to 40 degrees. it measures rain-rates up to a threshold 4 times higher than the previous device and allows to identify transient single satellite anomalies.

References and acknowledgments

Adirosi, E., L. Facheris, F. Giannetti, S. Scarfone, G. Bacci, A. Mazza, A. Ortolani, and L. Baldini, 2020: Evaluation of rainfall estimation derived from commercial interactive DVB receivers using disdrometer, rain gauge, and weather radar. IEEE Trans. Geosci. Remote Sens., https://doi.org/10.1109/TGRS.2020.3041448

Ortolani, A., Caparrini, F., Melani, S., Baldini, L., Giannetti, 2021: An EnKF-based method to produce rainfall maps from MW-link signal attenuation. Journal of Hydrometeorology, https://doi.org/10.1175/JHM-D-20-0128.1

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