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Estimating water vapour along the radio path between two LEO satellites through multifrequency differential power measurements

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The Normalized Differential Spectral Attenuation (NDSA) concept was proposed in 2002 by the authors for tropospheric water vapour sounding by means of a couple of LEO (Low Earth Orbit) satellites (one carrying a transmitter, the other a receiver and operating in the K_u/K bands) in limb geometry. In those years, in the course of the ACE+ mission studies (second call for proposal of the ESA Earth Explorer Opportunity Mission), the problem arose of the severe impact of scintillation due to tropospheric turbulence on the water vapour estimates provided by radio occultation measurements made in limb mode between two LEO satellites. In following ESA studies (AlmetLeo - 2004, ACTLIMB -2009) it was demonstrated that NDSA, thanks to its normalised differential approach, is effective for limiting scintillation and for estimating the Integrated Water Vapor (IWV) along the propagation path between the two LEO satellites. NDSA relies on the conversion of a spectral parameter (the spectral sensitivity S), into the IWV through IWV-S relationships. S is a finite-difference approximation of the derivative of the spectral attenuation at a given frequency f_o, normalized to the spectral attenuation itself. To measure Sat f_o,it is required that two tone signals with equal power at relatively close frequencies f_1 and f_2 ($f_1 > f_2$) symmetrically placed around f_o are simultaneously transmitted. The two pertinent received powers P_1 and P_2 are simultaneously measured and S is provided by:

$$S = \frac{P_2 - P_1}{(f_1 - f_2)P_2}$$

From the very beginning of the NDSA studies, it was evident that in ideal measurement conditions (no disturbance at the receiver nor propagation impairments) S is tightly correlated to the IWV. To verify this, we accounted for natural variations of the atmospheric conditions by generating simulated spherically symmetric atmospheres using real radiosonde profiles. We computed IWV along the radio path and simulated S separately obtaining IWV-S relationships at various altitudes through regression methods. In particular, the ESA-AlMetLEO study yielded a significant insight into such relationships up to 12 km using the K-Ku bands, while the ESA-ACTLIMB study offered the opportunity to investigate the potential of 179 to 182 GHz (M band) for estimates from 10 km upwards, exhibiting a significant robustness to scintillation fluctuations.

However, two problems affected the reliability of the empirical IWV-S relations found and have been faced by us during the on-going ESA-ANISAP study: 1) the accuracy of the radiosonde data used to derive them was not uniform in the northern and southern hemisphere, and so their positions; 2) the number of radiosonde samples above 10 km was limited, and their reliability scarce, which affected the analysis of the IWV-S relations in the M band. To overcome both problems, instead of radiosonde data, we utilized atmospheric pro?les equally distributed on a global Earth scale as derived from ECMWF atmospheric analysis data. Such database includes pressure, temperature, humidity, liquid water, ice water and wind components in 8 global datasets in 4 days amid of each of the four seasons and at two time layers (12:00 UTC and 24:00 UTC). In this work, we show the main results of the global scale analysis of the IWV-S relations up to 20 altitude. We point out that NDSA requires a multi-frequency approach to provide reliable IWV estimates up to 20 km, and that S estimates at 17, 19 and 21 GHz are essential to provide IWV profiles in the lower troposphere through linear relationships, while the M band channels (179 and 182 GHz) can be reliably exploited still through linear relationships above 10 km where the water vapour content is smaller. We also demonstrate that an additional spectral sensitivity channel at 32 GHz is very effective both to detect the presence of liquid water along the link and to correct the IWV overestimates caused by such presence when using S measurements in the K/Ku band (17, 19 and 21 GHz).