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ESTIMATION OF THE TROPOSPHERIC LIQUID WATER CONTENT BETWEEN TWO COROTATING LEO SATELLITES THROUGH POWER RATIO MEASUREMENTS

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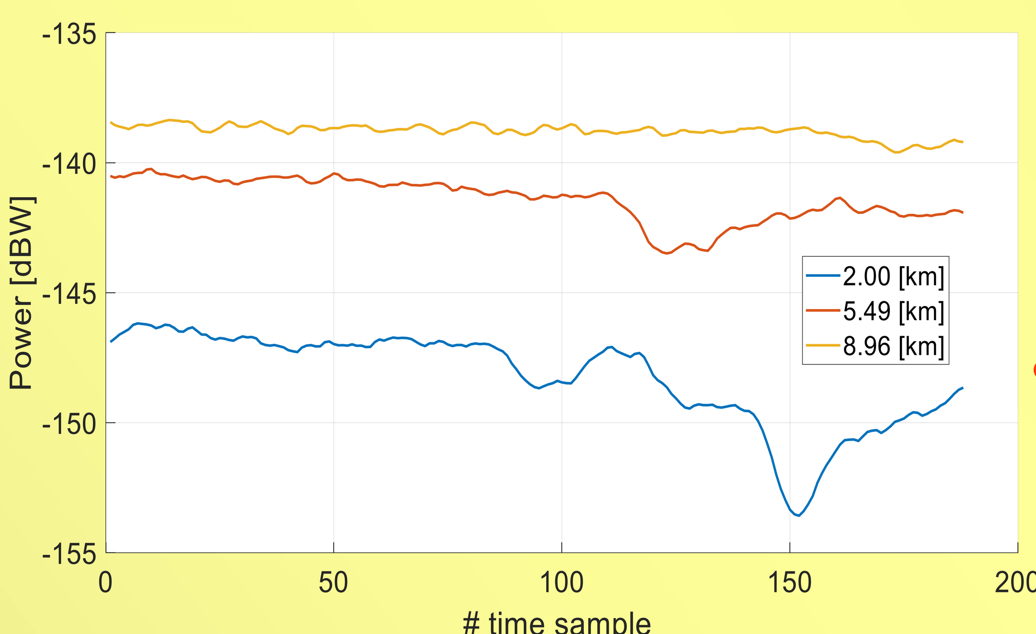
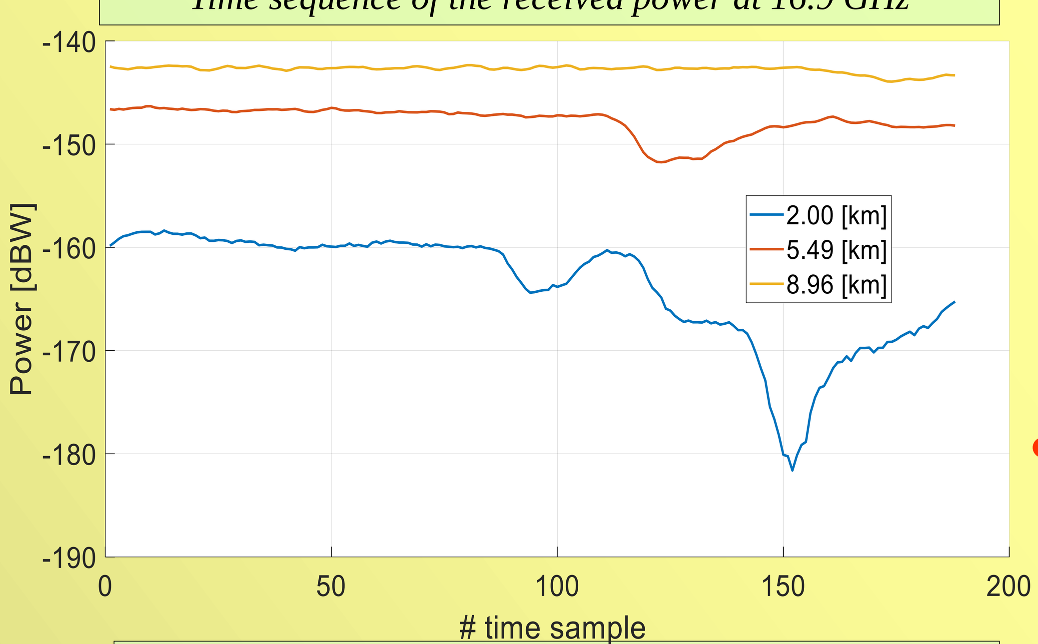
ABSTRACT

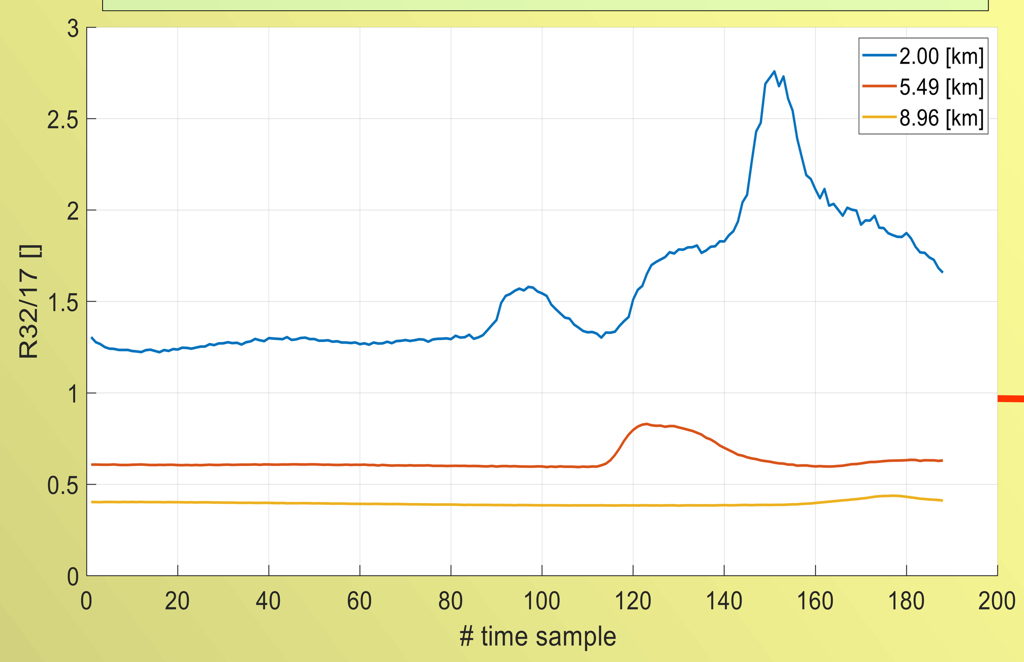
We show some results of the analysis carried out to check the possibility to provide an estimate of the Integrated Liquid Water (ILW) content along a microwave link established between the multifrequency transmitter and the receiver on board a couple of Low Earth Orbiting (LEO) satellites. The ILW estimate is provided through the power ratio of the received signals at 32 and 17 GHz. The results have been obtained using a simulation tool developed for LEO satellites orbiting in the same plane and along the same angular direction (co-rotating satellites), assuming some high-resolution atmospheric scenarios generated by using the WRF (Weather Research and Forecasting) numerical weather prediction model.



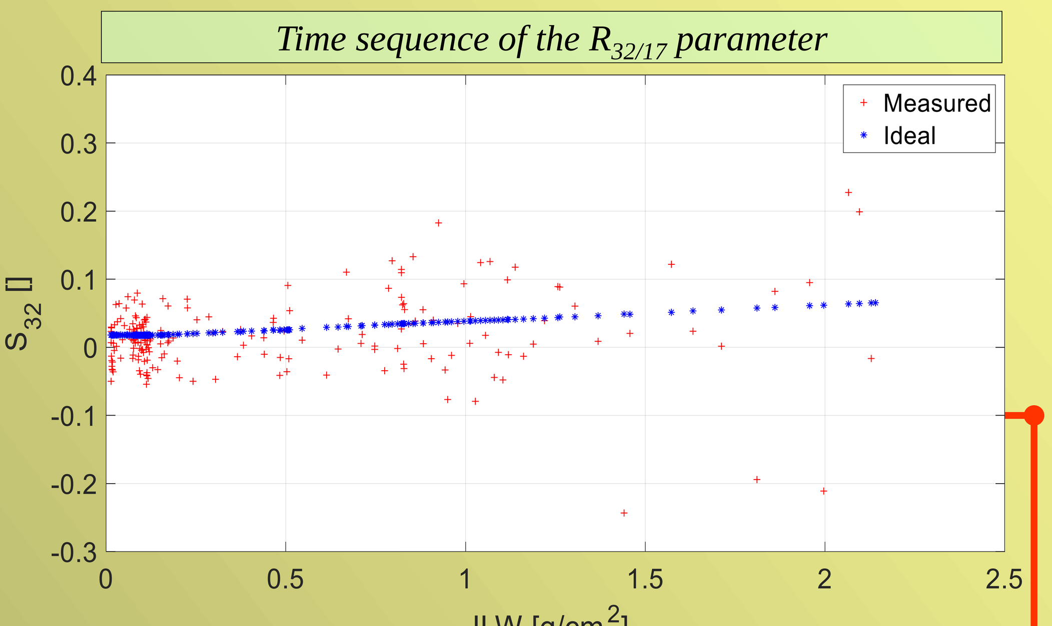
Time sequence of the received power at 16.9 GHz



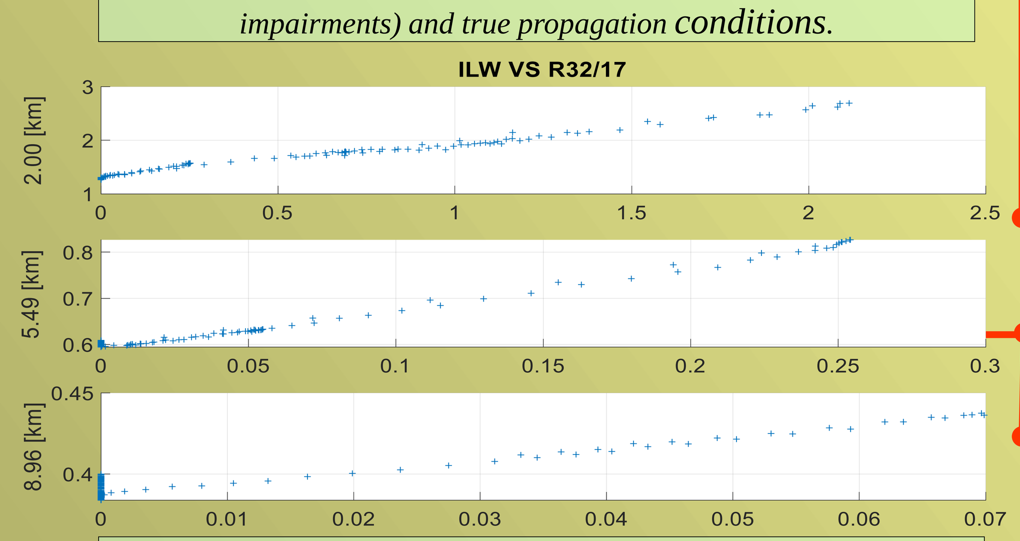
Time sequence of the received power at 31.8 GHz



Time sequence of the $R_{32/17}$ parameter



Scatter plots between ILW and S_{32} for all tangent altitudes in ideal (no impairments) and true propagation conditions.



Scatter plots between ILW and $R_{32/17}$ for the 3 tangent altitudes.

MAIN NOTES

- Some years ago some of the authors proposed the application of the so called Normalized Differential Spectral Absorption (**NDSA**) (a technique which allows to retrieve the integrated water vapor (IWV) along a radio link established between a transmitter Tx and a receiver Rx) to a constellation of **co-rotating (CO-ROT) satellites** carrying various numbers of Tx and Rx and orbiting in the same Low Earth Orbit (LEO) plane.
- The IWV estimates provided by the NDSA method are affected by the presence of Liquid Water (LW) along the radio link. Specifically, the impact of LW on the IWV estimates provided by NDSA in the 17-21 GHz frequency range is a positive bias which is proportional to the total Integrated Liquid Water (ILW) content along the radio link.
- The use of the spectral sensitivity measured in the 30-32 GHz range was also proposed for estimating the path integrated LW, and possibly for correcting the IWV measurements.
- Here we show the limitation of the use of the spectral sensitivity for estimating the ILW and that it is possible to estimate the ILW by means of the power ratio of the received signals at 31.8 GHz and at 16.9 GHz

We generated some reference atmospheric scenarios over Italy. The WRF (Weather Research and Forecasting) numerical weather prediction model was used, initialized with the IFS (Integrated Forecasting System) model of the ECMWF.

The reference atmospheric model used in this work pertains to July 24, 2020. That day was characterized by an advancing warm front, capable of generating convection with a limited vertical speed, and by the rapid passage of a precipitating event on the central and northern part of the Italian peninsula.

We consider a constellation geometry with one transmitting satellite and three receiving ones on the same circular orbit. The satellites are placed so that the tangent altitudes of the three radio links are 2, 5 and 9 km.

We assume that the initial and final positions of the satellites are such that the Tx-Rx link at 2 km tangent altitude intersects the points (34°, 10 km) and (46°, 10 km), respectively. In this manner, all the radio links cross the considered annular sector spanning [34° – 46°] in latitude and [2-10] km in altitude, and the number of time samples for each Tx-Rx link is 158.

The following parameters have been set:

- satellites co-orbiting on a circular polar orbit at constant angular speed, having a revolution period of approximately 90 min;
- Earth radius: 6378 km;
- satellites orbit radius: 6651 km (273 km altitude);
- integration time at the receiver: Ts = 0.5 s;
- transmitted power: 3 dBW for each tone;
- frequencies for power measurement: 16.9, 17.1, 31.8 and 32,2 GHz;
- Tx and Rx antenna gains: 26.4 dB.
- System noise equivalent temperature: 25.3 dBK

Let us define P_{17} and P_{32} as the received powers at 16.9 and 31.8 GHz, respectively, and $R_{17/32}$ as follows:

$$R_{32/17} = -10 \log(P_{32}/P_{17}) \qquad (1)$$

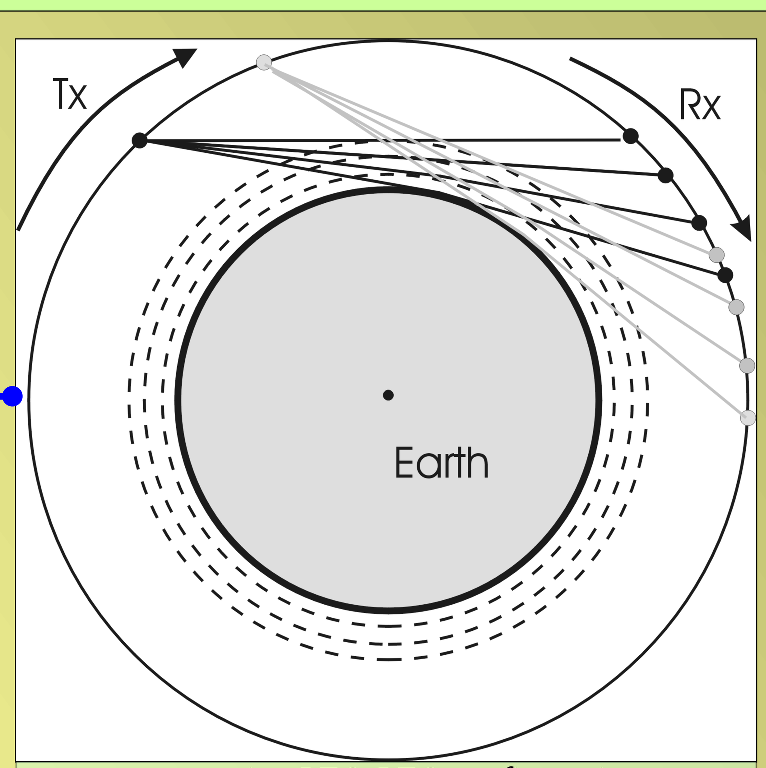
And the spectral sensitivity S32 as:

$$S_{32} = 1 - P_{32.2}/P_{31.8} \qquad (2)$$

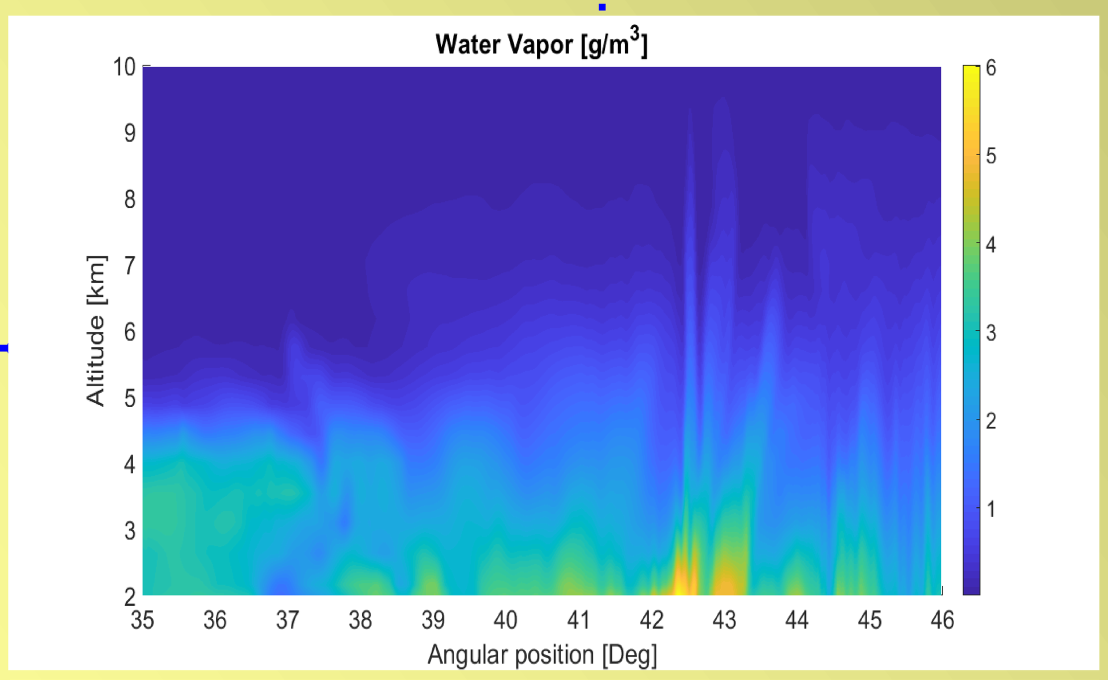
where $P_{32.2}$ and $P_{31.8}$ are the received powers at 32.2. and 31.8 GHz, respectively.

The scatter of the 'real' measurements of S_{32} with respect to the ideal ones is excessive, which does not allow one to provide a direct estimate of ILW with acceptable precision

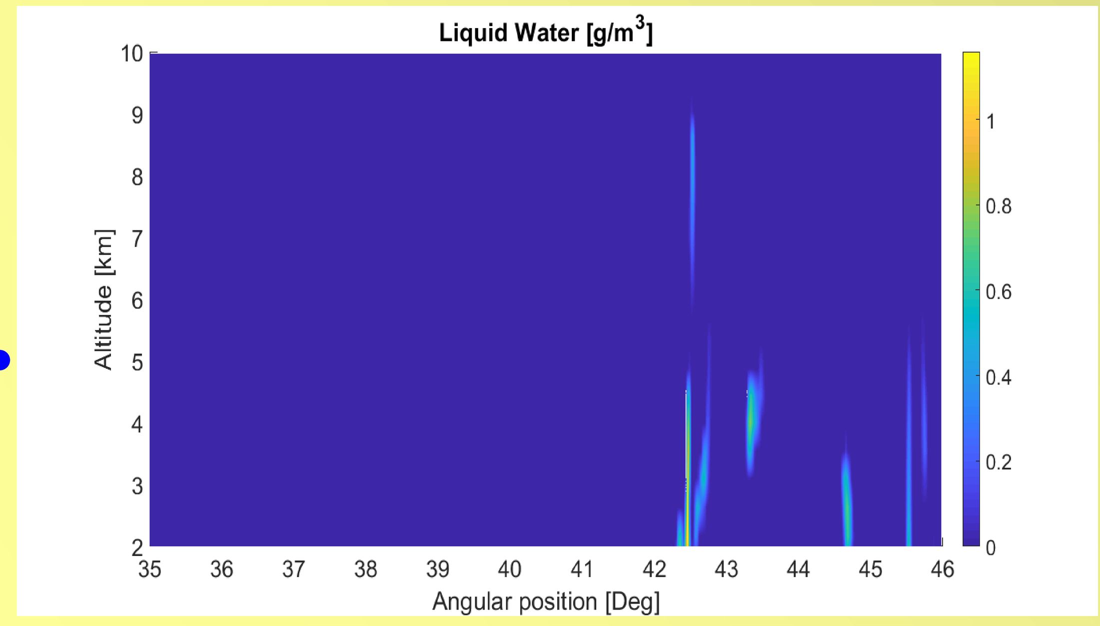
The scatter plots between ILW and $R_{32/17}$ separately for the three tangent altitudes show that a linear trend is evident, and this suggests that the measurement of $R_{32/17}$ even in realistic conditions (i.e., accounting for impairments) could provide a direct estimate of the ILW via a linear conversion law.



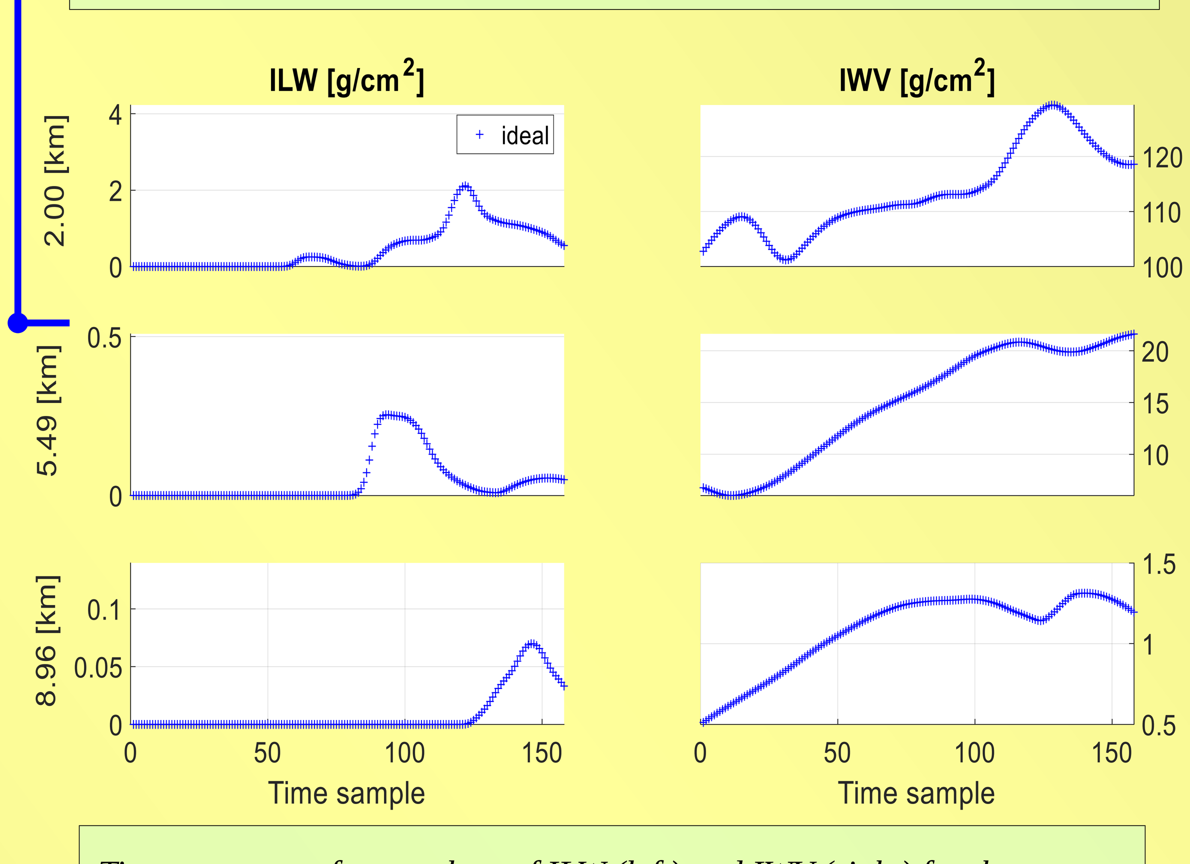
co-rotating LEO-LEO configuration



Reference field of Water Vapor related to the atmospheric status on July 24, 2020 - 11:00:00 UTC at 11.15° East longitude



Reference field of Liquid Water related to the atmospheric status on July 24, 2020 - 11:00:00 UTC at 11.15° East longitude



Time sequence of true values of ILW (left) and IWV (right) for the tangent altitudes (top to bottom) of 2.00, 5.48 and 8.96 km

CONCLUSIONS

The results presented concerning the possibility to estimate the ILW along multifrequency radio links between transmitters and receivers on board LEO satellites are promising. The results have been obtained using a signal propagation simulation tool developed for co-rotating satellites and in a context defined by high resolution atmospheric scenarios which have been generated through the WRF numerical weather prediction model. As a matter of fact, the ILW content appears to be linearly related to both the spectral sensitivity parameter S_{32} defined in (2) and the power ratio $R_{32/17}$. However, the simulations carried out under the hypothesis of realistic values of the signal impairments parameters have shown that the estimate of $R_{32/17}$ is much more reliable than that of S_{32}. Consequently, the ILW estimate is expected in general to be more reliably obtained by resorting to $R_{32/17}$ rather than to S_{32}. In order to be able to assess the overall expected performance of the use of $R_{32/17}$ to provide ILW estimates, a further analysis step is needed - analogous to the one that the authors carried out for determining the IWV-S relations to derive IWV estimates from S measurements - by involving as many different atmospheric conditions as possible which can be considered as representative of different Earth locations and seasons of the year.

CONSORZIO LaMMA

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