Thesis title :

Remote sensing of water vapor in cloudy atmospheres

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ABSTRACT

According to the latest IPCC report (2021), the role of clouds in the climate system remains a challenge for climate modelling. The formation and evolution of clouds in the atmosphere largely depend on the availability of water vapor in the atmosphere which is expected to increase in a warmer climate. Consequently, gaining insights into the spatial and temporal variability of atmospheric water vapor within a cloudy atmosphere is essential for improving our understanding of mechanisms that link water vapor and clouds. This in turn is necessary to refine and better constrain small-scale physical cloud models and numerical weather prediction models.

Water vapor amount and profiles are currently mainly retrieved using microwave or infrared sounders at spatial resolutions of about ten kilometers. However, studying the interactions between clouds and water vapor requires higher spatial resolutions that can be achieved by passive radiometers in the solar spectrum such as the Multi-view, Multi-Chanel, Multi Polarization Imaging Mission (3MI) in the EUMETSAT Polar System or the water vapor imagers in the Cluster for Cloud evolution, ClImate and Lightning mission (C^3IEL). Based on the heritage of POLDER, the use of radiance in a near-Infrared water vapor absorbing channel enables the retrieval of vertically integrated water vapor content in clear sky conditions. Recent developments carried in preparation of C^3IEL mission demonstrate the feasibility of using an optimal estimation method to retrieve the water vapor content above clouds assuming they are plan-parallel. However, these studies have not yet investigated the benefit of multi-angle observations provided by the two missions.

The main objectives of the thesis will be, first, to investigate and quantify the advantage of multi-angular information to increase the accuracy of water vapor retrieval above clouds, and secondly to implement a methodology applicable to the aforementioned missions. First, the benefits will be evaluated in horizontally uniform water vapor fields above plan-parallel homogeneous clouds. However, clouds and in particular convective clouds are not plan-parallel and water vapor around these clouds can be horizontally variable due to entrainment and detrainment processes. Assessments of the accuracy of the water vapor retrieval in a more realistic configuration will be performed, either by considering horizontal variabilities in the water vapor fields or non-flat and heterogeneous clouds. The studies will be conducted through numerical simulations of realistic observations computed with the three-dimensional radiative transfer code, 3DMCPOL and cloud fields generated by a high-resolution numerical cloud model. Strategies to mitigate or account for the 3D structure of water vapor fields or clouds will be elaborated using the potential of the multi-angular measurements and, if necessary, the information existing at a sub-pixel scale, from the CLOUD imagers in case of C3IEL or from Met-Image in case of 3MI. Innovative retrieval approach such as multipixel optimization, tomographic or neural network based approaches will be investigated and tested to propose a practical implementation applicable to measurements provided by 3MI, C^3IEL and more generally to multi-angular observations.