MEASUREMENTS OF HUMIDITY IN THE ATMOSPHERE AND VALIDATION EXPERIMENTS (MOHAVE, MOHAVE II): RESULTS OVERVIEW

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ABSTRACT

The Measurements of Humidity in the Atmosphere and Validation Experiments (MOHAVE, MOHAVE-II) inter-comparison campaigns took place at the Jet Propulsion Laboratory (JPL) Table Mountain Facility (TMF, 34.5ºN) in October 2006 and 2007 respectively. Both campaigns aimed at evaluating the capability of three Raman lidars for the measurement of water vapor in the upper troposphere and lower stratosphere (UT/LS). During each campaign, more than 200 hours of lidar measurements were compared to balloon borne measurements obtained from 10 Cryogenic Frost-point Hygrometer (CFH) flights and over 50 Vaisala RS92 radiosonde flights. During MOHAVE, fluorescence in all three lidar receivers was identified, causing a significant wet bias above 10-12 km in the lidar profiles as compared to the CFH. All three lidars were reconfigured after MOHAVE, and no such bias was observed during the MOHAVE-II campaign. The lidar profiles agreed very well with the CFH up to 13-17 km altitude, where the lidar measurements become noise limited. The results from MOHAVE-II have shown that the water vapor Raman lidar will be an appropriate technique for the long-term monitoring of water vapor in the UT/LS given a slight increase in its power-aperture, as well as careful calibration.

1. INTRODUCTION

Due to its abundance and radiative properties, water vapor has long been identified as a key constituent of the atmosphere and in particular, plays a major role in the radiative balance of the upper troposphere and lower stratosphere [1]. Over the past decade, a long-term increase in the lower stratospheric water vapor has been detected, the cause of which is not fully understood. Due to its very low concentration near and above the tropopause and because of its very high spatial and temporal variability in the troposphere, measuring water vapor and understanding and quantifying accurately its role on climate remains a challenging exercise [2]. In order to contribute to this understanding as well as to support the validation of satellite measurements, the Network for the Detection of Atmospheric Composition Change (NDACC, formerly known as NDSC), has recently considered including the water vapor measurements using Raman lidar in its suite of long-term measurements. Though most Raman lidars are dedicated to the measurement of lower tropospheric water vapor, several have recently been developed to measure water vapor in the UT/LS. To estimate the capability of three of these lidars, two major validation campaigns, called "Measurements of Humidity in the Atmosphere and Validation Experiments" (MOHAVE and MOHAVE-II) took place in October 2006 and October 2007 respectively. Both campaigns involved several remote sensing and in-situ techniques and were very successful with more than 40 balloon launches and over 200 hours of lidar measurements for each campaign. An overview of the campaigns achievements is described in this extended abstract.

2. INSTRUMENTS DEPLOYEMENT

2.1 Lidars

Two mobile lidars from NASA-Goddard Space Flight Center (GSFC), namely the "AT" lidar, and the "SRL", later redesigned into the "ALVICE" system [3], were deployed for the MOHAVE campaigns at the JPL Table Mountain Facility in California, where a third water vapor Raman has been operating since 2005 [4]. All three lidars participating to the campaigns utilize the same technique, i.e., calculating the ratio of the Raman-backscattered signals returned respectively at 387 nm by atmospheric nitrogen, and 407.5 nm by atmospheric water vapor [5]. There are two limitations with this technique. First, the instrument loses sensitivity as we approach the tropopause due to the decrease of water vapor mixing ratio. Second, the instrument needs careful calibration, often requiring an external source of information, for example a water vapor measurement from radiosonde. These lidar instruments can acquire data up to 14-18 km but the measurements at such high altitudes could not be validated until the MOHAVE and MOHAVE-II campaigns due to the lack of correlative measurements having the required accuracy in the upper troposphere.

2.2 In-situ balloon measurements

The Cryogenic Frost-point Hygrometer (CFH) is presently considered as one of the most reliable instruments to measure water vapor in the UT/LS, and will be considered herein as the reference [6]. A total of ten CFH were launched between October 19 and 28, 2006 (MOHAVE), and 10 more were launched between October 6 and 17, 2007 (MOHAVE-II). Vaisala RS92 radiosondes were also widely used. A total of 41 RS92 provided by JPL and 8 provided by GSFC were launched during MOHAVE, and another 50 provided by JPL were launched during MOHAVE-II. In order to study the repeatability of the RS92 measurements, eleven balloon payloads during MOHAVE included two RS92. All CFH were launched with at least one RS92 on the same payload.

2.3 Other instruments

Two GPS receivers (one located at TMF and operated by JPL, and another brought by the GSFC staff) produced integrated water vapor data during MOHAVE. A microwave instrument operated for NDACC at TMF by the Naval Research Laboratory routinely produces water vapor profiles above 30 km. An experimental, non-validated, water vapor total column product was provided for MOHAVE. The GPS and microwave data can be used to help calibrate the water vapor Raman lidars (not discussed in this abstract). To complement the already large set of instruments and techniques, the JPL tropospheric ozone lidar was run simultaneously with the water vapor lidars during both campaigns and one ECC ozonesonde was launched simultaneously with each CFH (results not shown here).

3. SUMMARY OF OPERATIONS

Both MOHAVE and MOHAVE-II were planned identically. Because the water vapor lidar measurement is background-noise limited, highest priority was given to five October nights centered on the new moon, i.e., October 19-23, 2006 and October 9-13, 2007. Additional priority was given to nights with best Aura satellite overpass. The GSFC/SRL mobile lidar suffered major damage during transportation at the start of first campaign, and the system had to be modified to be operational during MOHAVE. In 2007 the instrument was entirely re-built before it came back to TMF for MOHAVE-II (ALVICE). During MOHAVE, the first high-priority night was cloudy for half of the time but the next fifteen nights remained entirely clear, and very stable. Weather during MOHAVE-II was less stable and led to high variability in atmospheric water vapor at very short timescales. At least one or two RS92 were launched each night during MOHAVE, and four were launched (in average) each night during MOHAVE-II. During MOHAVE two RS92 were often mounted on the same payload to study the repeatability of the radiosonde measurement. One CFH was launched every night, with the exception of one night during MOHAVE and one night during MOHAVE-II during which 2 CFH were launched. The CFH launch times were optimized to coincide with the best Aura-MLS overpasses. Most nights, all three lidars were operated all night long. However the lidar signals were systematically analyzed over shorter time windows to better match the in-situ measurement times. The standard analyzing procedure was to provide a 1-hour-integrated lidar profile starting at the time of each balloon launch. Additional integration windows were chosen to provide nightly-integrated profiles (profiles reaching higher altitudes) and to provide short-integration profiles (to study short-term variability within the same night).

4. RESULTS

4.1 MOHAVE

Figure 1 shows the average during MOHAVE of the four profiles for which all instruments and techniques measured simultaneously (i.e., must include 1 CFH, 2 RS92, and 3 lidars each time).

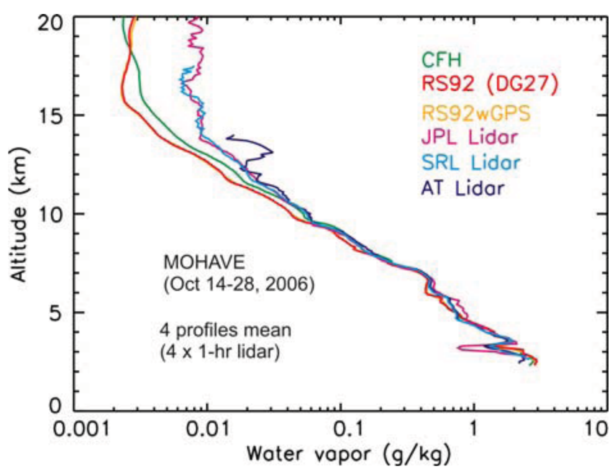
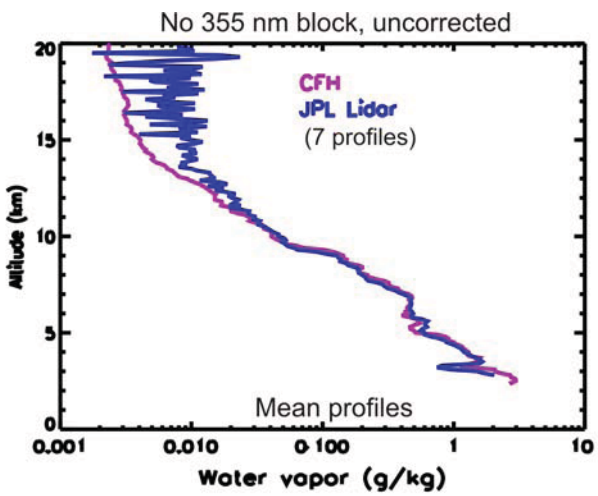


Figure 1: Mean of four water vapor profiles simultaneously measured by CFH, three lidars, and two RS92 radiosonde systems during MOHAVE.

If one takes the CFH as the reference, a clear wet bias can be observed for all lidars above 10-12 km, and a dry bias is observed on the RS92 averaged profiles above 10 km. The dry bias was expected and is typical of the non-corrected RS92 water vapor measurements [7]. The perfect agreement observed on figure 1 between the two radiosondes installed on each payload is typical of the entire campaign, and illustrates well the good repeatability of the RS92 measurements. The observed lidar wet bias was quickly thought to be a consequence of residual fluorescence in the lidar receiver optics. Fluorescence was immediately suspected because all three lidar systems are pushed to their photons detection limits and therefore become very sensitive to residual fluorescence. For the JPL lidar, the fluorescence was identified in the fiber optic connecting the large telescope to the receiver box. Figure 2 illustrates the impact of this fluorescence and how it was successfully removed. The top panel shows results obtained with the initial lidar configuration (average of 7 profiles measured simultaneously with a CFH) while the bottom panel shows results obtained after a 355 nm blocking filter was installed at the entrance of the fiber optic (average of 3 profiles). As can be seen the wet bias above 12 km was completely removed after the blocking filter was installed.



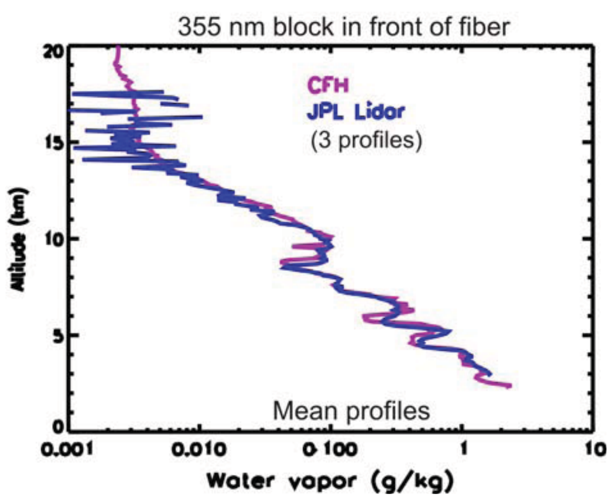


Figure 2: Mean water vapor profile measured simultaneously by CFH and by the JPL lidar. a) measured with the lidar original configuration. b) measured with a 355-nm blocking filter in front of receiver

4.2 MOHAVE-II

Because fluorescence was clearly identified during MOHAVE, all three lidar receivers were reconfigured during the first half of 2007 with the objective of being operational and "fluorescence-free" during MOHAVE-II in October 2007. Specifically, the JPL lidar receiver was modified to avoid any contamination by the 355-nm signal inside the main receiver path (fiber optic and subsequent splitters). The 355-nm signal was therefore re-directed out of the main path immediately after the focus of the telescope, and before the entrance of the fiber optic. Improved (non-fluorescent) coated optics were also used. Figure 3 is similar to figure 1, but this time for MOHAVE-II (10 simultaneous profiles with CFH). A clear improvement in the agreement between the CFH and all three lidars can be seen, unfortunately at the expense of the signal-to-noise ratio and the resulting cut-off altitude (at least 2-km lower than during MOHAVE). As during MOHAVE, the RS92 uncorrected mean profile is too dry in the upper troposphere. Using the results from both the 2006 and 2007 MOHAVE and WAVES inter-comparison campaigns, an empirical correction [7] can be performed, leading to a perfect agreement between the corrected RS92 ("RS92Milo"in figure 3) and the CFH profiles.

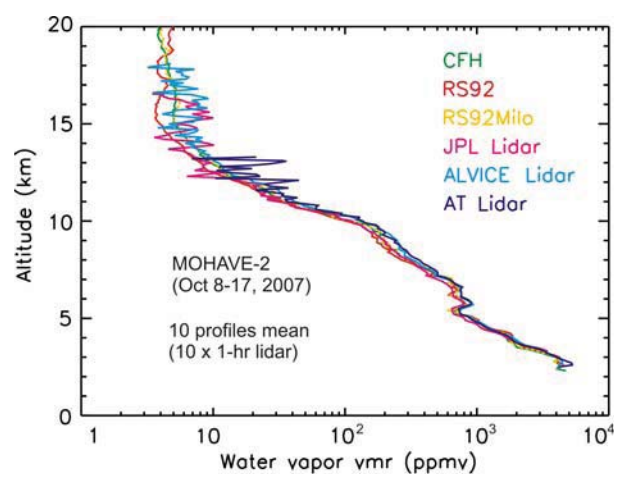


Figure 3: Mean water vapor profile simultaneously measured by CFH, three lidars, and RS92 radiosonde during MOHAVE-II.

In addition to evaluate the performance of the lidars in the upper troposphere, MOHAVE-II allowed to evaluate the accuracy of the lidar calibration (calibration obtained by normalizing the lidar profiles to the closest available radiosonde measurements). Figure 4 shows a time-altitude color contour plot of water vapor measured by the JPL lidar on October 10, 2007. The superimposed black solid curves represent the corresponding water vapor perturbation from the nightly mean as measured by each of the four radiosondes launched that night. The dotted black lines indicate the time-altitude position of the balloon and represent the zero-water vapor perturbation. Significant short timescale and small vertical scale variability is clearly observed (>150% within 2 hours), typical of that observed throughout MOHAVE-II. Considering that the radiosondes were launched from the lidar site, this figure raises an important issue of lidar calibration accuracy. Multiple calibration experiments performed during MOHAVE-II showed that this accuracy ranges between 15% and 30% depending on the calibration method and lidar integration times used (not shown here, see another extended abstract in the present proceedings). Due to the very high natural variability of atmospheric water vapor, careful calibration procedures are therefore needed to insure long-term stability of the lidar calibration.

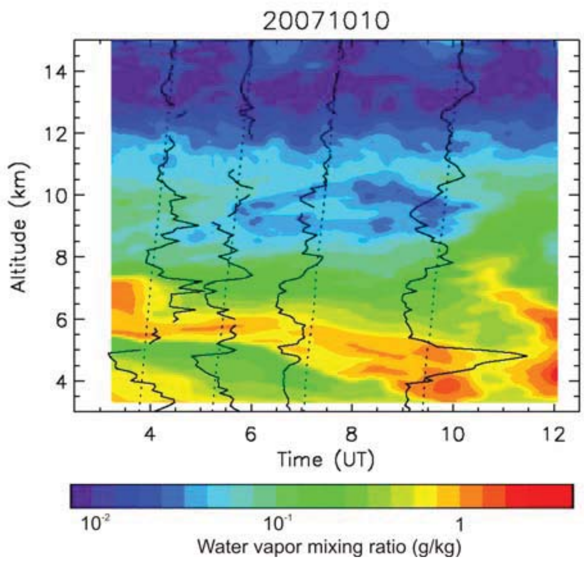


Figure 4: Time-altitude 2D color contour plot of water vapor mixing ratio measured by the JPL lidar on the night of October 10, 2007. The superimposed black solid curves represent the departure from nightly mean as measured by the four radiosondes launched on that night. The black dotted lines show the time-altitude position of the balloon, and the zero-departure in water vapor.

5. CONCLUSION

The MOHAVE and MOHAVE-II campaigns deployed at the JPL-Table Mountain Facility in October 2006 and 2007 respectively allowed significant progress towards the evaluation of the water vapor Raman lidar capability in the UT/LS. MOHAVE allowed identifying residual fluorescence in the lidar receivers, causing a significant wet bias in the water vapor profiles above 10-12 km altitude as compared to the CFH. Following the results of MOHAVE all three participating lidars were reconfigured in early 2007, and re-deployed for MOHAVE-II with "fluorescence-free" receivers. As anticipated the lidar profiles then agreed very well with the CFH up to 13-16 km altitude. Calibration experiments were performed during MOHAVE-II, revealing the critical need for a careful calibration approach, especially if the measurements are dedicated to the long-term monitoring of water vapor. Given an anticipated increase in power-aperture in the years to come, the Raman lidar technique appears to be very promising for the detection of future water vapor trends in the UT/LS.

Acknowledgments: The research described in this abstract was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

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