

liquid water path estimates in marine stratus

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1. Introduction

Marine boundary-layer liquid water paths (LWPs) determine to first-order the radiative impact of marine stratus upon the global climate, and are integral to cloud, aerosol, and precipitation process studies. The latter often invoke the assumption that adiabatic quantities are well-mixed with height. This implies that testing for the limits of the adiabatic assumption by comparing retrieved LWPs to those from an adiabatic ascent calculation can usefully establish the extent of non-adiabatic cloud processes.

In addition, a comparison of surface-based microwave radiometer-derived LWPs to adiabatic values may also aid in our assessment of microwave absorption models, both liquid and dry.

To date, the impact of microwave model improvements upon LWPs retrieved within marine stratus regions has not been evaluated, despite the climate ramifications.

We examine LWPs retrieved from surface-based microwave radiometer measurements made within the southeastern Pacific stratus region from the R/V Ron Brown. 3 gaseous absorption models, and 3 liquid dielectric models are evaluated. Well-characterized, overcast conditions and a well-mixed boundary layer ensure a physically-meaningful adiabatic LWP calculation.

This work has relevance for the first recent deployment of the ARM mobile facility to a marine stratus region; a similar analysis of the California and SE Pacific stratus regime can aid our understanding of the similarities and differences between the two regions.

Further details are available within a manuscript of the same title recently submitted to JGR, available through <http://www.rsmas.miami.edu/users/pzuidema>

2. Data

Two microwave radiometers were used, one with channels at 20.6 and 31.65 GHz (referred to as the "Hughes" radiometer), and a radiometer similar to what is in use at ARM sites with channels at 23.8 and 31.4 GHz (referred to as the "mailbox" radiometer). We focus on a 6-day period when the research vessel was stationary. During this time, the water vapor channel measurements of both radiometers compared well to each other, and an offset of ~2 K was evident in the mailbox radiometer relative to the Hughes radiometer. Small-scale variability in the system gain (i.e., instrument noise) contributes approximately 0.33 K to the Hughes 20 GHz brightness temperature variability, and 1.1 K to the Hughes 31 GHz T_b variability; the latter exceeds that at the ARM sites. We further averaged the data into 10-minute time intervals. The total LWP uncertainty, at this time scale, from both Hughes radiometer frequencies, is approximately 15 $g\ m^{-2}$. The best LWP estimate for the 6-day time period is a blending of data from both radiometers; for the part of the time that the Hughes radiometer could not be calibrated, the time series was augmented by corrected mailbox measurements.

& Approach

A physical-iterative retrieval approach was applied towards retrieving LWPs from the MWR brightness temperatures. Sounding temperature and humidity data, interpolated from 8-daily rawinsondes to a 10-minute time resolution, served as physical inputs, along with cloud boundaries derived from ceilometer and a cloud radar. The sondes were of type Vaisala RS-80 and manufactured after Vaisala implemented a corrective sealed sensor cap into its packaging.

First, 3 gaseous absorption models were evaluated, by comparing brightness temperatures calculated from the sondes to MWR observations. Then, 3 liquid dielectric models were evaluated. The impact of different (gas, liquid) models upon the retrieved LWPs were compared to each other and to the adiabatically-calculated LWPs for a well-mixed, consistently overcast day with little precipitation.

A resulting final time series of LWPs is then compared to satellite values, and a larger comparison to adiabatic values and to a measure of drizzle, derived from cloud radar reflectivities, is done.

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4. Liquid dielectric models

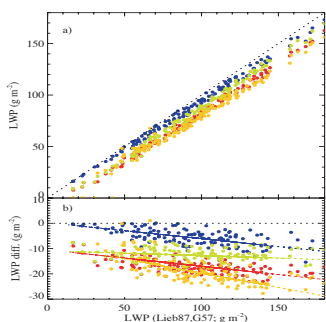


Fig. 2

a) LWPs retrieved for Oct. 15 using (Lieb87, L91), (R98, L91), (R98, G57), and (Lilj05, R03) (blue, red, green, and dark yellow circles)

b) Similar to a), but showing the differences between the LWPs retrieved w/ each model and the (Lieb87, G57) model.

The 3 liquid dielectric models examined include the Grant et al. (1957) model, the Liebe et al. (1991) model further modified according to Liebe et al. (1993), and the Rosenkranz (2003) model (pers. comm.). These are hereafter referred to as G57, L91, and R03.

The more recent the (gas, liquid) model combination, the lower the retrieved LWPs. The (Lieb87, G57) combination produces the highest LWPs, and the (Lilj05, R03) combination the lowest; the two differ by ~10 $g\ m^{-2}$ + 0.1LWP_{Lieb87, G57}

As shown in Fig. 3, a better correspondence to the theoretical adiabatic LWP values exists with the more recent models. The G57 liquid model overestimates LWP, but the comparison to the adiabatic numbers is too crude to support the choice of either the L91 or R03 above the other. These two models differ by ~4 $g\ m^{-2}$ per 100 $g\ m^{-2}$, with the R03 model producing smaller LWPs.

5. Relationship to adiabatic values

a. microwave model evaluation

Fig 3 shows retrieved LWPs versus adiabatic values for a) (Lieb87, G57), b) (Lieb87, L91), c) (R98, L91), and d) (Lilj05, R03) models. Mean retrieved LWPs indicated in right-hand corner.

=> We choose the R03 model; L91 model equally acceptable)

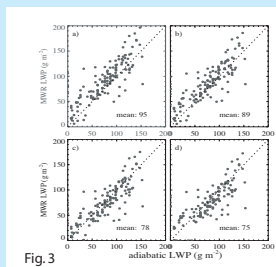


Fig. 3

b. thermodynamical evaluation

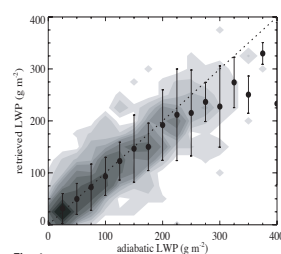


Fig. 4

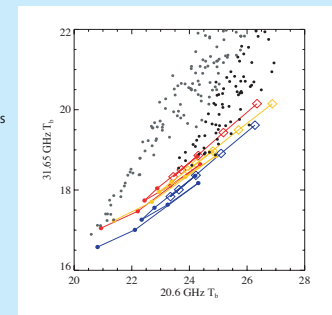
Fig. 4 shows contoured frequencies of retrieved versus adiabatic LWPs, Oct. 16- Oct. 22. This includes times with drizzle. Retrievals invoke (Lilj05, R03) (gas, liquid) models.

The retrieved values, despite being decreased from earlier estimates using older microwave absorption models, are still remarkably close to adiabatic values for LWP up to 150 $g\ m^{-2}$, decreasing to ~85% for a LWP of 250 $g\ m^{-2}$.

3. Gaseous Absorption Models

The 3 models evaluated include: the Liebe and Laton (1987) model, the Rosenkranz (1998) model, and the Liljegren et al. (2005) model. These are hereafter referred to as the Lieb87, R98, and Lilj05 models.

No unambiguous clear-sky soundings (as determined from ceilometer, cloud radar, and MWR measurements) were identified. However, we can still examine whether sonde-calculated values of brightness temperature (which don't include liquid) are lower than the measured T_b (which do include a response to liquid). This is shown in Fig. 1 below for 2 days of data. The 11 sondes sampled a range of water vapor paths from 1.4 to 2.0 cm.



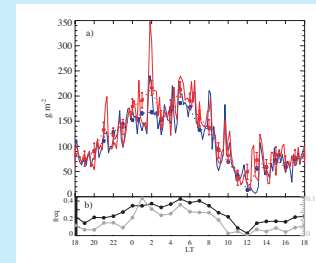
Measured T_b on Oct. 14 and 15 (black and grey circles), calculated clear-sky T_b using Lieb87, R98, and Lilj05 models (blue, red, dark yellow lines), with circles and squares indicating coincidence with sondes.

Differences in T_b calculated from the 3 models can reach 0.5 K (R98 - Lieb87), corresponding to a LWP difference of ~15 $g\ m^{-2}$. The best-fit to the bottom envelope of measurements is provided by the Lilj05 model (dark yellow line). This model is similar to the R98 model at low water vapor paths, but has a shallower slope than either R98 or Lieb87. The Lilj05 model has been shown to model the clear-sky 31 GHz T_b s particularly well (Mattioli et al., in press), and a conclusion that the R98 model overestimates the 31 GHz T_b while the Lieb87 model underestimates is also consistent with Marchand et al. (2003).

=> The Liljegren et al (2005) gaseous absorption model performs the best of the 3 models evaluated.

6. Diurnal Cycle, inc. drizzle

Fig. 5 shows the diurnal cycle in the retrieved and adiabatic LWPs, and in the frequency of occurrence of drizzle, where two cloud radar reflectivity thresholds, -17 dBZ and 0 dBZ, indicate light and heavy drizzle (black and grey resp.). The diurnal cycle is averaged over 6 days, at a 10-minute time resolution.



The largest deviation from adiabatic values occurs between 2-7 AM local time, when drizzle is most prevalent. Heavy drizzle possesses a more pronounced diurnal cycle than light drizzle and is most prevalent between 1-8 AM local time. Light drizzle does not necessarily encourage deviations of the cloud from adiabatic values, which are more linked to the occurrence of heavy drizzle.

References:

- Liebe, H., and D. Layton, 1987: Millimeter wave properties of the atmosphere: Laboratory studies and propagation modeling, NTIA Rep. 87-24, 74 p.
- Liebe, H., G. Hufford, and T. Manabe, 1991: A model for the complex permittivity of water at frequencies below 1 THz. *Int. J. Infrared Millimeter Waves*, **12**, 659-675.
- Liljegren, J. S., Boukabara, K., Cady-Pereira, and S. Clough, in press: The effect of the half-width of the 22-GHz water vapor line on retrievals of temperature and water vapor profiles with a twelve-channel MWR. *IEEE Trans. Geo. Remote Sens.*
- Marchand, R., T. P. Ackerman, E. Westwater, S. Clough, K. Cady-Pereira, and J. Liljegren, 2003: An assessment of microwave absorption models and retrievals of cloud liquid water using clear-sky data. *J. Geophys. Res.*, **108**, doi: 10.1029/2003JD003843.
- Mattioli, V., E. Westwater, S. Gutman, and V. Morris, in press: Forward model studies of water vapor using scanning MWRs, GPS, and radiosondes during the C1C experiment. *IEEE Trans. Geosci. Remote Sens.*, pp. 1-15.
- Rosenkranz, P., 1998: Water vapor microwave continuum absorption: A comparison of measurements and models. *Radio Sci.*, **33**, 919-928.