# Parameterization of liquid water path fluctuations in non-precipitating stratocumulus

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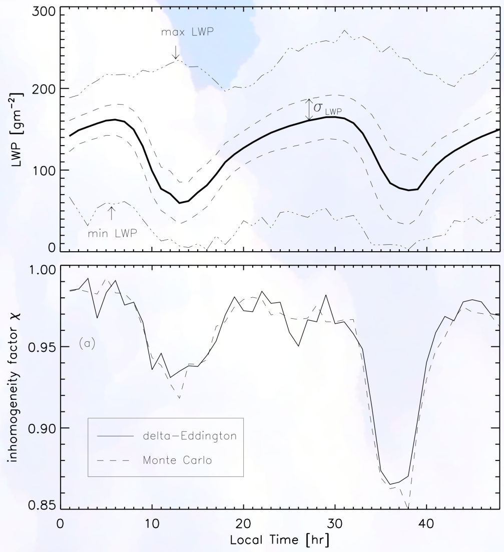
## Stratocumulus albedo bias

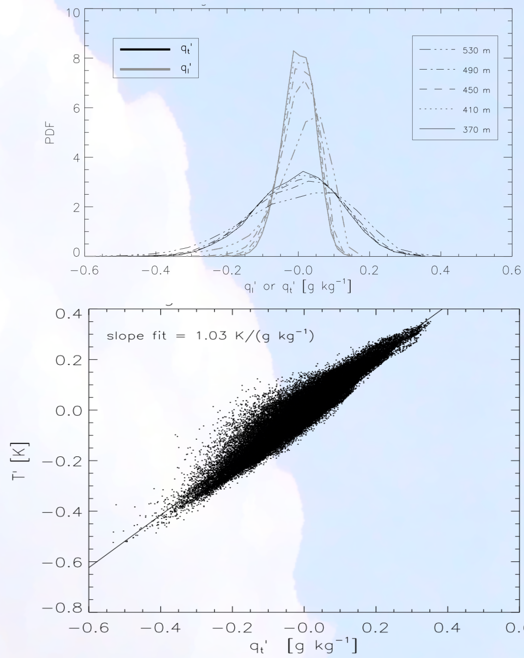
Solar radiative transfer through stratocumulus cloud layers is larger for a horizontally inhomogeneous cloud layer than for a plane-parallel cloud containing the same volume mean liquid water content. In large-scale models this albedo bias effect can be taken into account by multiplying the modeled optical depth $\tau$ by a cloud inhomogeneity correction factor $\chi<1$. A large-eddy simulation of the diurnal cycle of stratocumulus as observed during FIRE I shows that the mean and the variance of the optical depth control the magnitude of $\chi$.




Figures: Time series of the mean, standard deviation, minimum and maximum cloud liquid water path (LWP) and the inhomogeneity correction factor $\chi$.

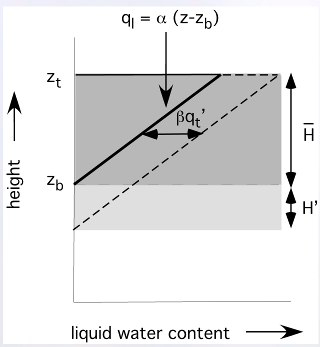
## Temperature and humidity

Liquid water fluctuations are smaller than total specific humidity fluctuations because of the temperature effect on the saturation specific humidity.




Figures: PDFs of the liquid and total water content ($q_l$ and $q_t$, resp.), and the total water content and temperature correlation in the middle of the cloud layer at 24 hr local time.

## Cloudy sub-column model




**Model assumptions**
We parameterize $q_l'=\beta q_t'$. In each cloudy sub-column total water content fluctuations are constant with height. Sub-column liquid water vertical gradients are equal to the horizontal mean value.

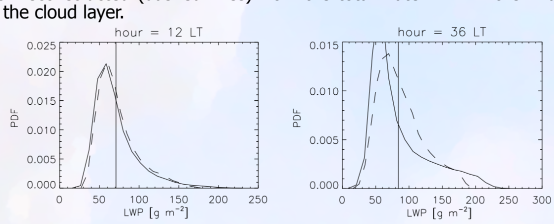
**Thermodynamics**
The liquid water potential temperature reads $\theta_l=\theta-L_v/c_p q_l$.

From this definition follows
I. $T'=0 \rightarrow \beta=1$
II. $\theta_l'=0 \rightarrow \beta\approx0.4$

Because entrainment warming is strongly counteracted by longwave radiative cooling at the cloud top, $\theta_l$ fluctuations are rather small for the FIRE I stratocumulus case, and $\beta\approx0.4$.

## Conclusions

The PDF of the simulated LWP (solid lines in the figures below) can be well reconstructed (dashed lines) from the total water PDF in the middle of the cloud layer.




From the cloudy subcolumn model a simple parameterization for the variance of the LWP and optical depth (assuming a constant cloud droplet effective radius) is derived:

$$\overline{LWP'^2} = \left(\rho_{air}\overline{H}\beta\right)^2 \overline{q_t'^2} \quad , \quad \overline{\tau'^2} = \left(\frac{3\rho_{air}\overline{H}\beta}{2\rho_l r_{eff}}\right)^2 \overline{q_t'^2}$$

The total water variance can be computed from its prognostic equation (Tompkins, 2002).

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**References**
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Tompkins, A. M. , 2002: A prognostic parameterization for the subgrid-scale variability of water vapor and clouds in large-scale models and its use to diagnose cloud cover. *J. Atmos. Sci.*, **59**, 1917-1942.

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