Mixed Layer Model and Large Eddy Simulations of Stratocumulus Cloud Dissipation over the Coast

Mohamed S. Ghonima[1], Jan Kleissl[1] and Thijs Heus[2]

[1]Department of Mechanical and Aerospace Engineering, University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0411.

[2] Institute for Geophysics and Meteorology, University of Cologne, Pohligstr. 3, 50969, Cologne, Germany

Introduction

- Marine layer stratocumulus (MLS) is a common type of cloud found in many coastal regions. The breakup of such clouds once they move inland is hard to predict in numerical weather prediction (NWP) models.
- NWPs such as WRF, NAM and ECMWF, systematically under-predict cloud cover in North America and Europe when compared to satellite.
- The optically thick MLS clouds attenuate solar radiation significantly. Due to the high concentration of rooftop PV panels near the coast in California, accurate prediction of MLS breakup is essential for the integration of solar power generation onto the electric grid.
- In order to better understand the different physical processes affecting MLS cloud dissipation over land, two tools are employed in this study:
  1. **Large eddy simulations (LES)**
  2. **Mixed layer model (MLM)**

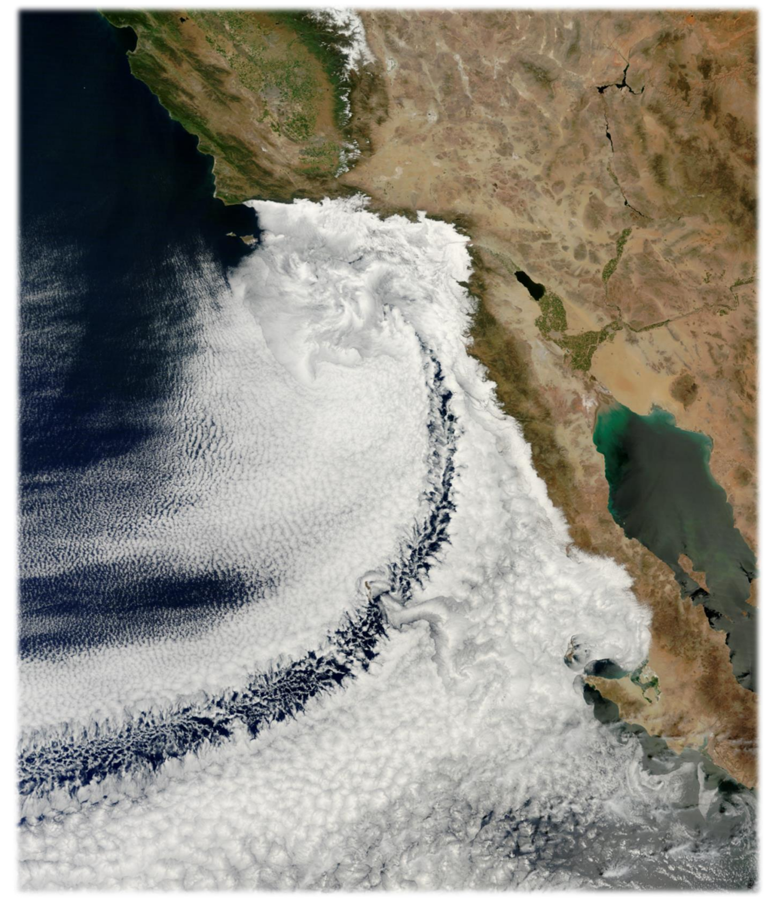

Figure 1: Stratocumulus cloud deck off the coast of California, captured by NASA's MODIS Terra satellite on April 14 2013.

Large Eddy Simulations

- Clouds dissipate within 4-5 hours after sunrise, which matches the dissipation times observed via satellites.
- Surface sensible heat flux warmed the boundary layer which caused the clouds to evaporate.
- At night, the turbulence was generated by longwave cooling in the cloud layer while during the day, the turbulence was mainly generated by the surface flux.

UCLA LES overview
Initial Atmospheric Profiles are based on CGILS s12
Start time=00:00 PST; run time=12 hours
$\Delta x = 25m, \Delta y = 25m, \Delta z = 5m$
Two moment rain scheme
Monte-Carlo spectral radiation scheme
Land surface model

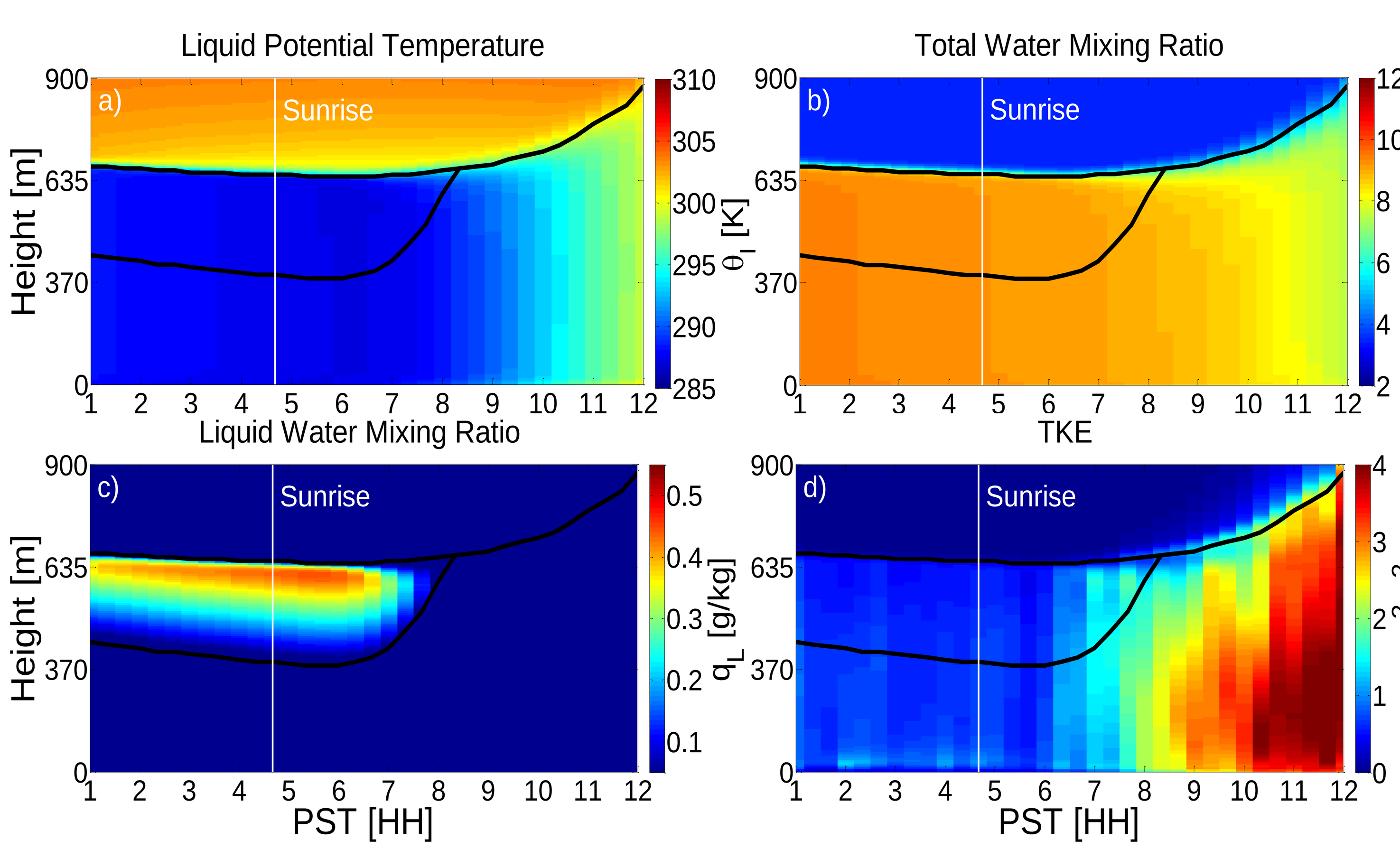

Figure 2: Vertical profile of a) liquid water potential temperature, b) total water mixing ratio, c) total liquid water mixing ratio, d) total kinetic energy plotted as a function of time, for a stratocumulus topped boundary layer over an interactive land surface. Solid lines represent the cloud base and top heights.

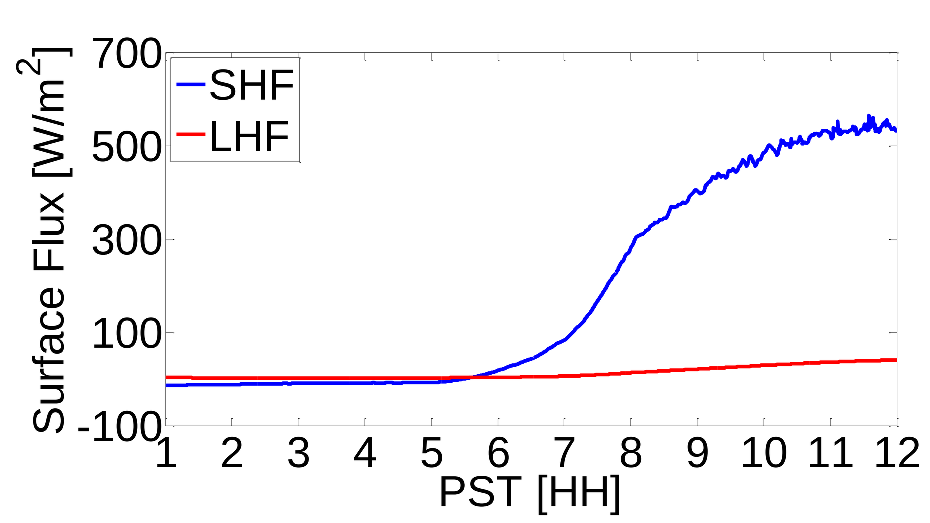

Figure 3: Surface sensible heat flux in blue and latent heat flux in red output from the LES run.

Mixed Layer Model

Cloud thickness tendency is expressed as:

$$\frac{\partial h}{\partial t} = \frac{\partial z_i}{\partial t} - \frac{\partial z_b}{\partial t}$$

$$\frac{\partial z_i}{\partial t} = w_e + w_s = 0$$

$$\frac{\partial z_b}{\partial t} = \frac{c_p \Pi_1}{z_i g}\left(1 - \frac{c_p R_v T_{cb}}{R_d L_v}\right)^{-1}\left(w_e \Delta\theta_l + SHF - \frac{1}{c_p \rho}\Delta F_{rad}\right) + \frac{g q_T}{z_i R_d T_{cb}}\left(1 - \frac{L_v R_d}{c_p R_v T_{cb}}\right)(w_e \Delta q_T + LHF)$$

MLM overview
Stand -alone model
Interactive long and short wave radiation scheme
Entrainment parameterized as a function of buoyancy flux
Surface flux parameterized as a function of Bowen ratio and net surface radiation

Variables	
z_i, z_b, h:cloud top and base height and thickness	SHF, LHF: sensible and latent heat flux
θ_l: liquid potential temperature	q_T, q_l: total water and liquid mixing ratio
TKE: Turbulent Kinetic Energy	β: Bowen ratio
F_{rad}: net radiation	w_e: entrainment velocity

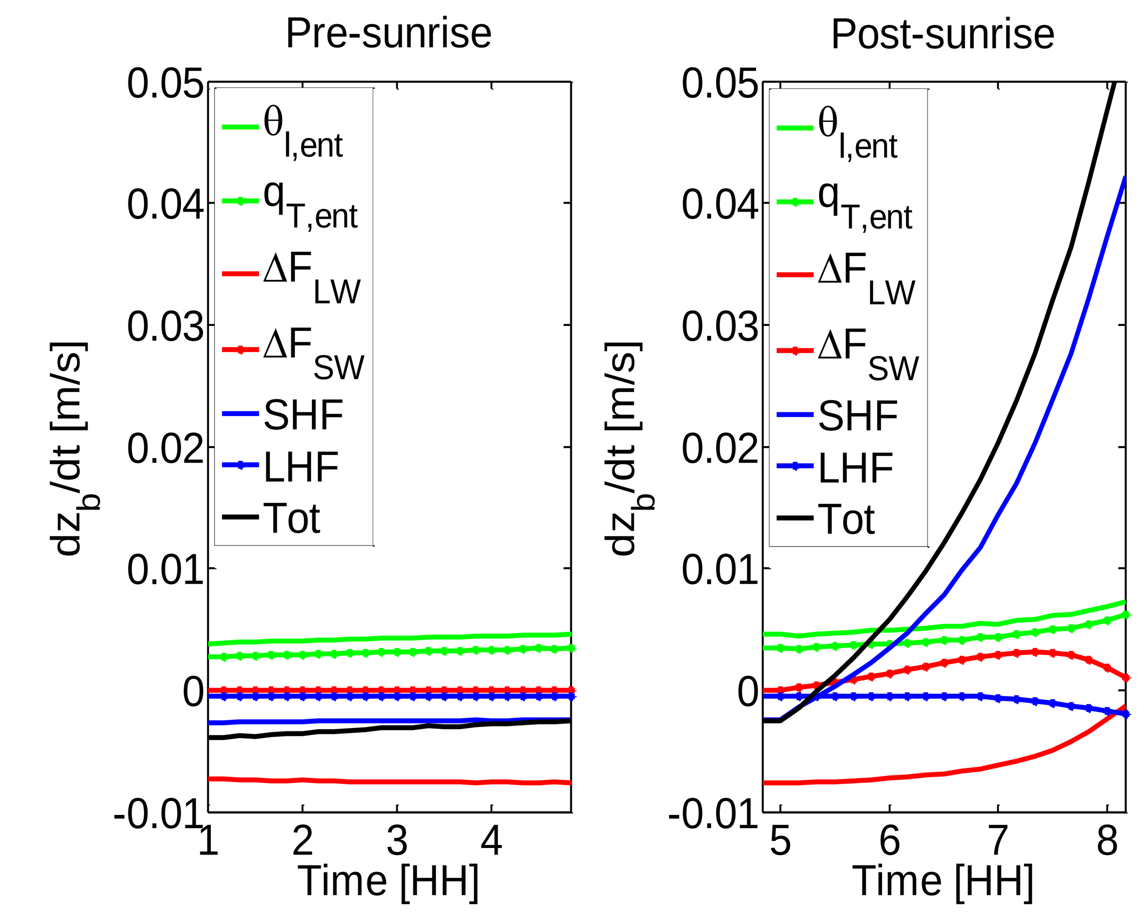

Figure 4: Effects of the different physical processes on the rate of change of cloud base height.

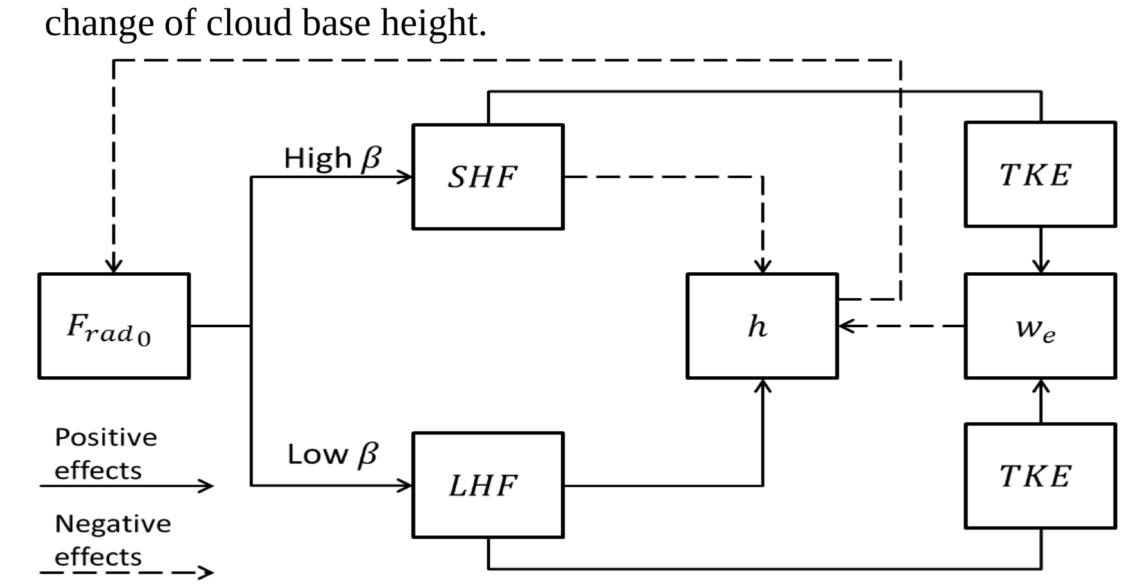

Figure 5: Feedback loops in the MLM. Solid lines denote positive effect, and dashed denote negative effect

Effect of Bowen Ratio on Cloud Dissipation

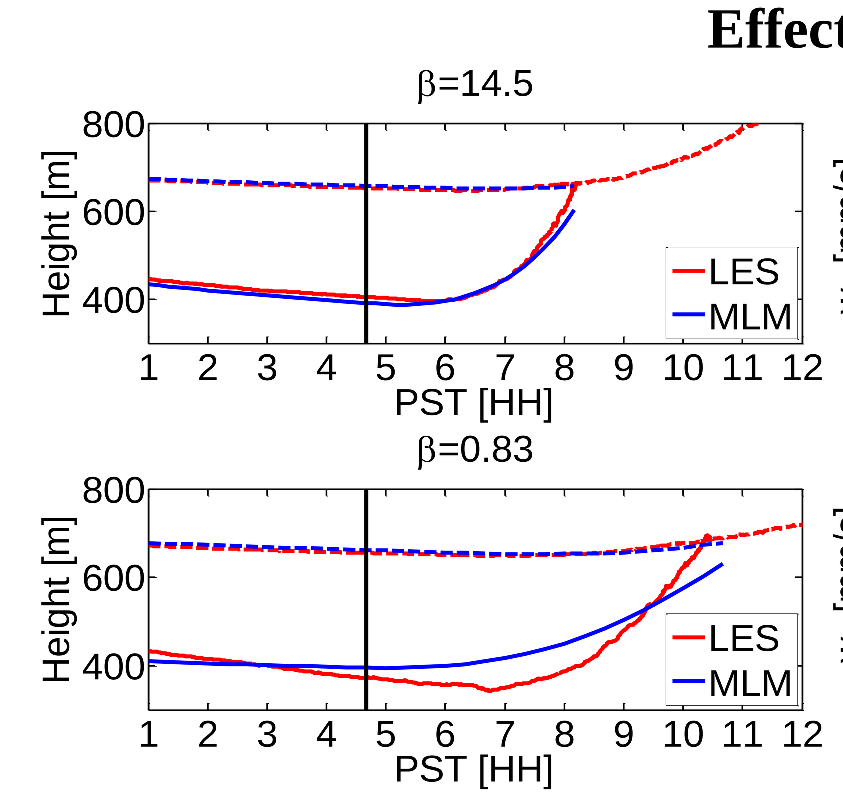

Figure 6: Comparison between LES (in blue) and MLM (in red) derived cloud base (solid line) and inversion height (dashed line)

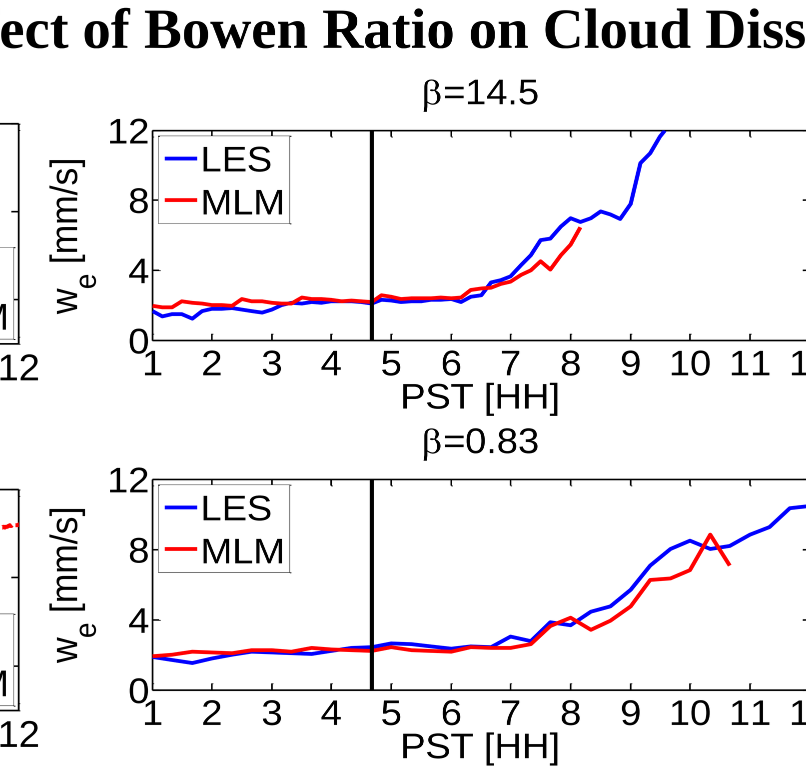

Figure 7: Comparison between cloud top entrainment velocities derived from LES (in blue) and MLM (in red)

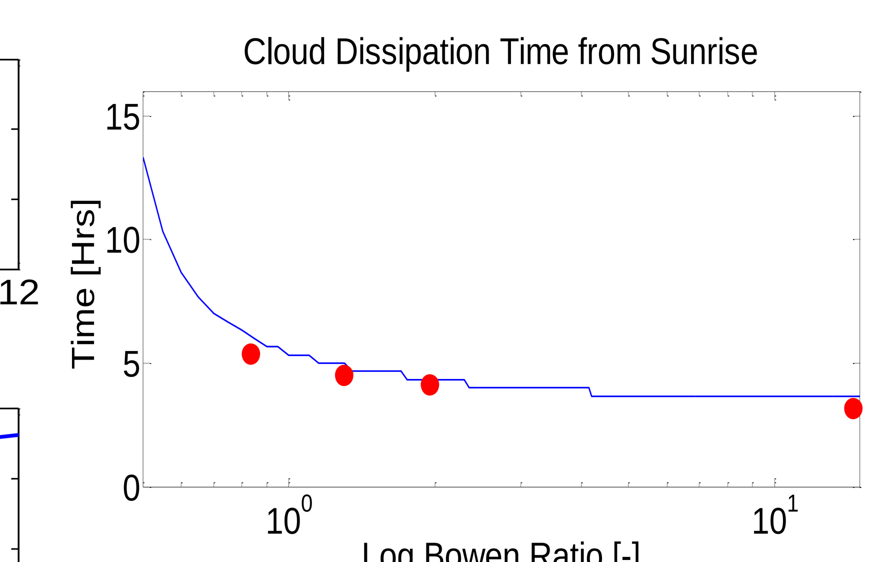

Figure 8: Cloud dissipation time as function of the log of the Bowen ratio computed by the MLM (blue line). LES simulated cloud dissipation times at different Bowen ratios (red dots)

Conclusions

- Stratocumulus dissipation times simulated by the LES and MLM matched reasonably well.
- Sensible heat flux and cloud-top entrainment were the dominant factors controlling the cloud decay at high Bowen ratios.
- At high Bowen ratios, the stratocumulus topped boundary layer system was found to be unstable and the cloud deck dissipates in a matter of hours after sunrise.
- As Bowen ratio decreases, the cloud lifetime increases and the stratocumulus topped boundary layer becomes more stable.

Acknowledgements

The authors would like to thank the CPUC California Solar Initiative RD&D program for funding.

Lead author contact: Mohamed Ghonima, Graduate Student, UCSD, mghonima@ucsd.edu