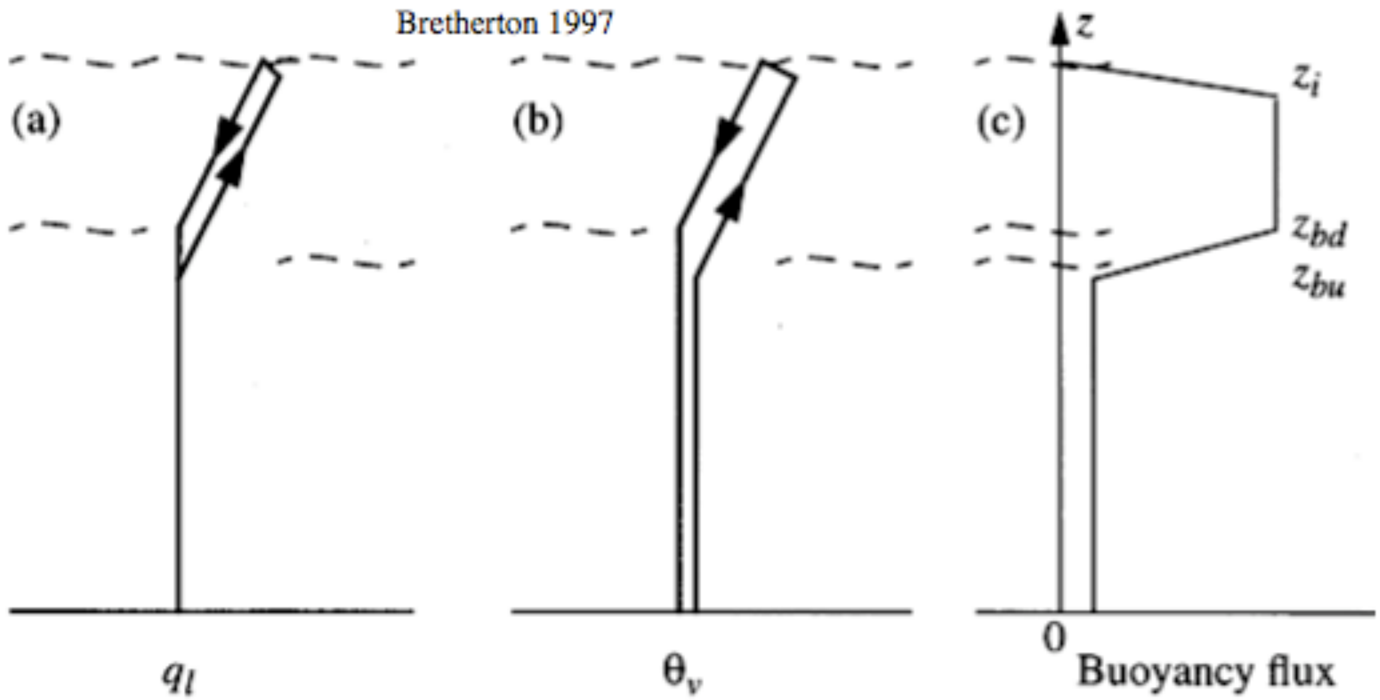
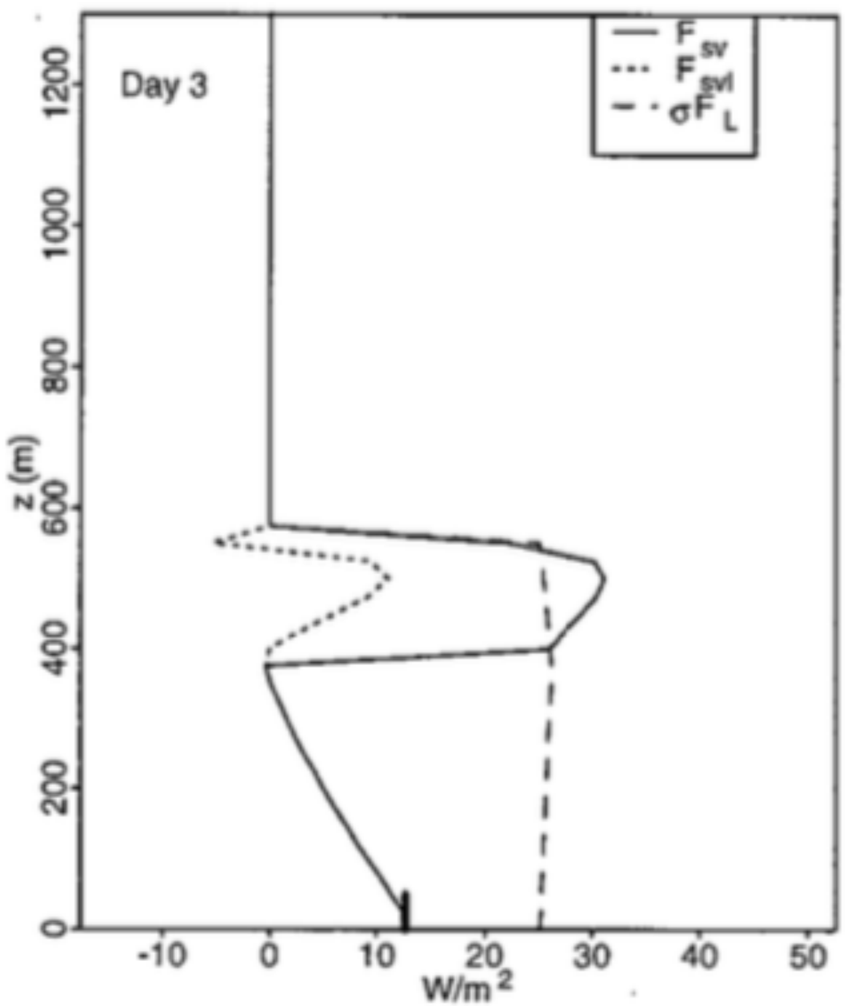
Parcel circuits in a Sc-capped mixed layer



- Note implied discontinuous increase in liquid water and buoyancy fluxes at cloud base ➔ turbulence driven from cloud, unlike dry CBL.
- Convective velocity $w_* \sim 1$ m s^{-1}:

$$w_*^3 = 2.5 \int_0^{z_i} \overline{w'b'} dz$$

Buoyancy flux profile in a Sc-capped mixed layer



Bretherton and Wyant 1997, Fig. 4

Solid: T_v flux (buoyancy flux)

Dotted: T_{vl} flux

Dashed: Scaled latent heat flux

Buoyancy flux minimum just below cloud base.

Buoyancy flux jump at cloud base is approx. proportional to LHF, with proportionality constant σ ~ 0.35.

Sc MLM entrainment closure

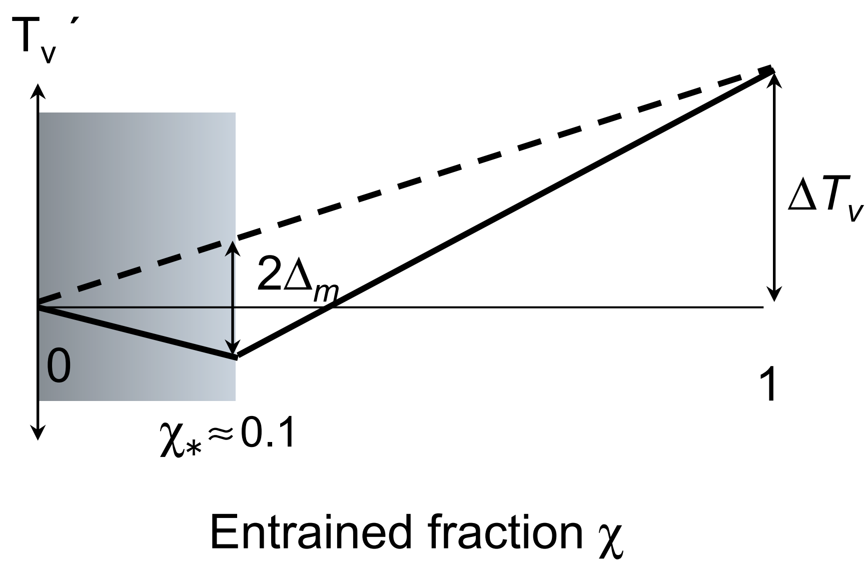
Nicholls-Turton (1986) entrainment closure
Fit to aircraft and lab obs and dry CBL

$$w_e = A\frac{w_*^3}{z_i \Delta b}, \quad A = 0.2(1 + a_2 E), \quad \Delta b = g\,\Delta T_v / T_0$$

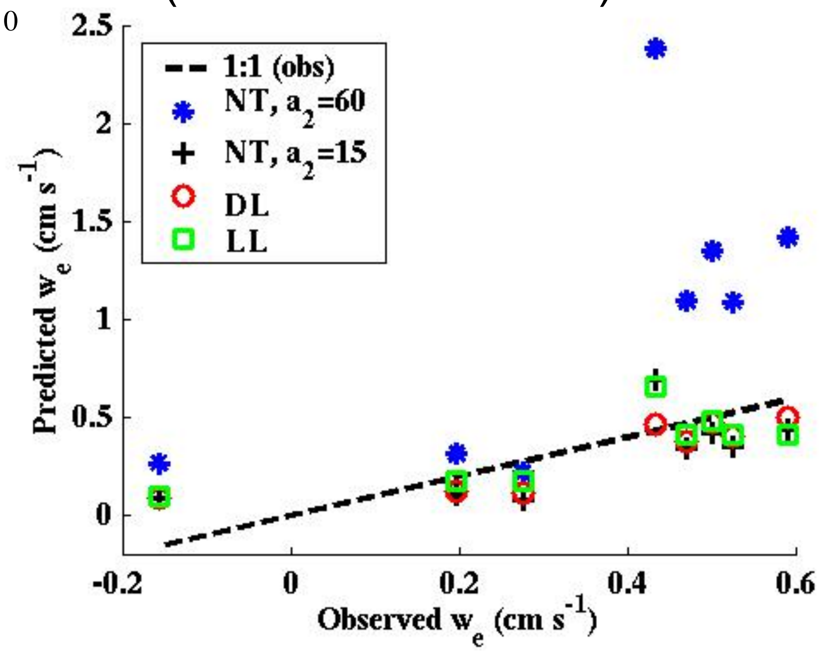
<u>Evaporative enhancement</u>: Less buoyant mixtures easier to entrain.

NT enhancement factor $E = \Delta_m/\Delta T_v$

a_2 = 15-60 ➔ A = 0.5 - 5 in typical Sc

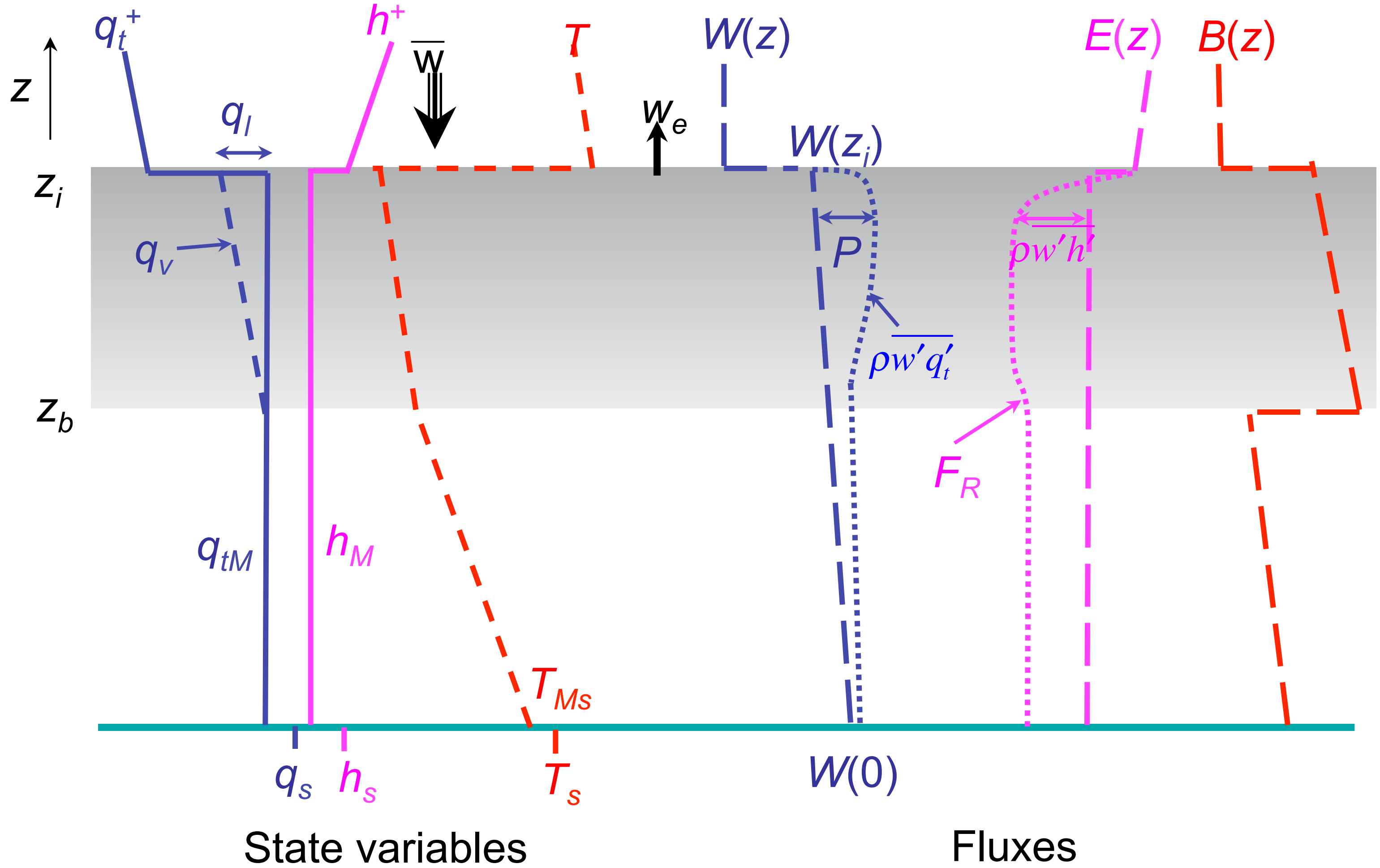


Observational test with
SE Pacific Sc diurnal cycle
(Caldwell et al. 2005)



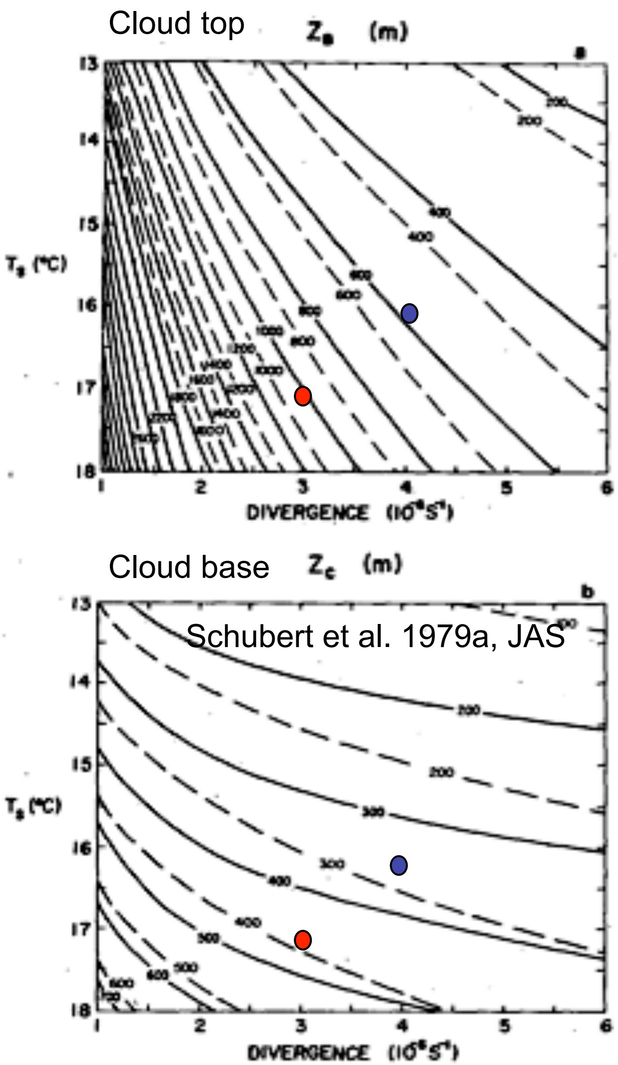
NT: Nicholls and Turton (1986)
DL: Lilly (2002)
LL: Lewellen&Lewellen (2003)

Profiles in a stratocumulus-capped mixed layer

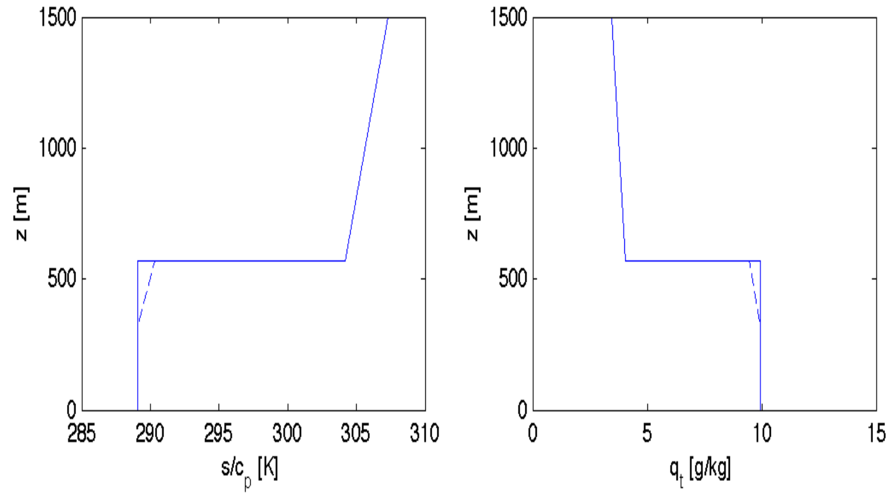


MLM examples

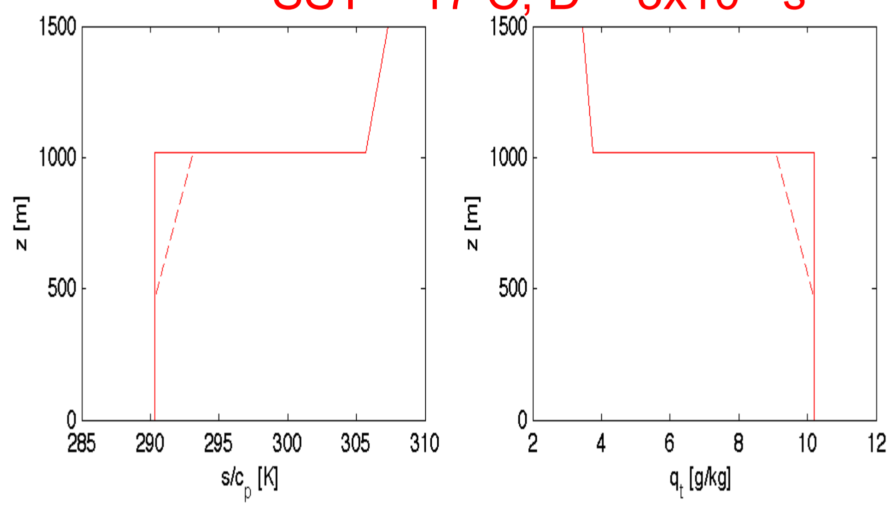
Steady-state solutions: Higher SST, lower divergence promote deeper mixed layer with thicker cloud.



SST = 16 C, D = 4×10^{-6} s^{-1}



SST = 17 C, D = 3×10^{-6} s^{-1}



MLM response to a +2K SST jump

Two timescales:

Fast internal adjustment

$t_b = z_i / C_T V \sim 0.5$ day

Slow inversion adjustment

$t_i = D^{-1} \sim 3$ days

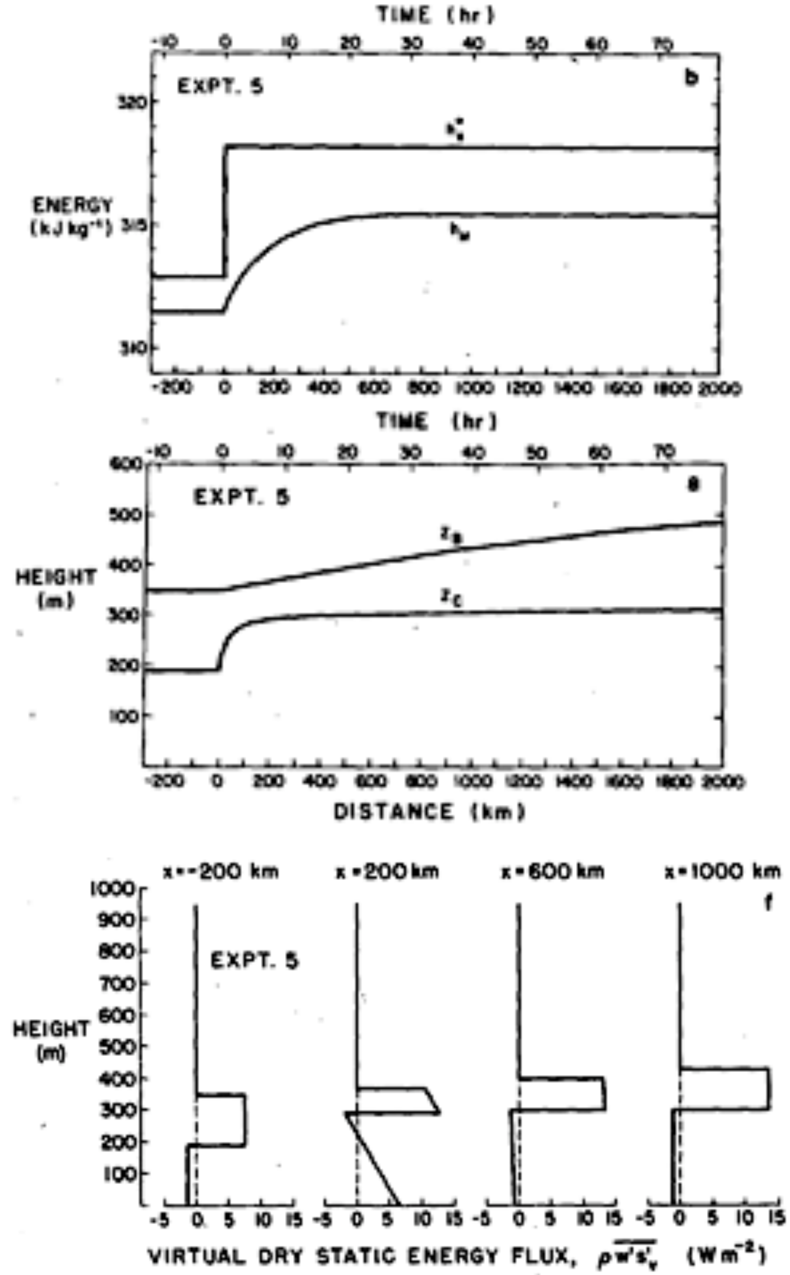
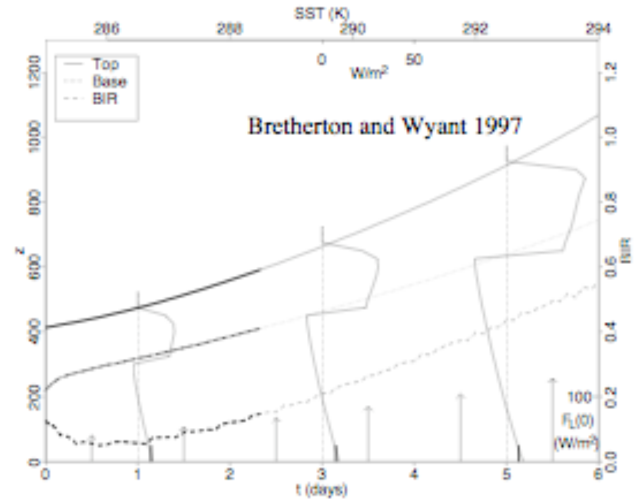


FIG. 11. Results for Experiment 5 (constant divergence, instantaneous 2°C increase in sea surface temperature).

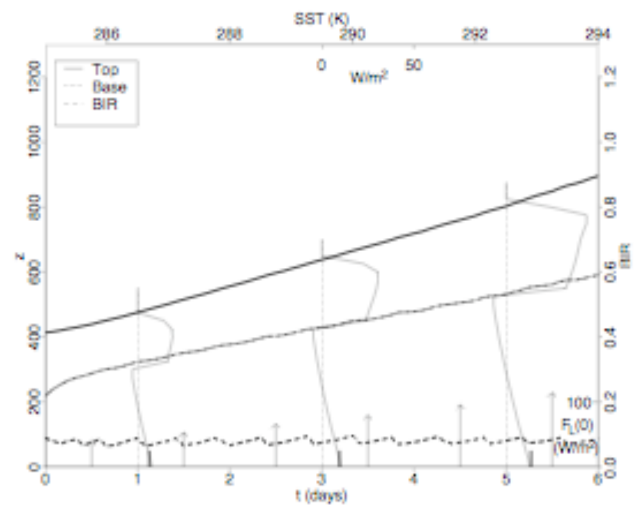
Schubert et al. 1979b JAS

Eddy velocity vs. flux-partitioning entrainment closures

- Overall MLM evolution is *not* too sensitive to closure because the MLM adjusts w_e to maintain **energy balance** in which entrainment warming roughly balances total BL radiative cooling (which mainly just cares about the cloud fraction).
- Subcloud buoyancy fluxes *are* sensitive to the closure. In simulations of MLM evolution over a warming SST, NT (w*) closure predicts increasing negative subcloud buoyancy fluxes as the BL deepens, implying decoupling after 2.2 days. The flux-partitioning closure cannot do this.



Mixed layer evolution with w_* closure with $A = 2$



Mixed layer evolution with flux-partitioning closure

MLM diurnal cycle

MLM prediction: cloud thickens during the day because of decreased entrainment, opposite to observations. The problem is that the mixed layer assumption breaks down during daytime.

Schubert 1976 JAS

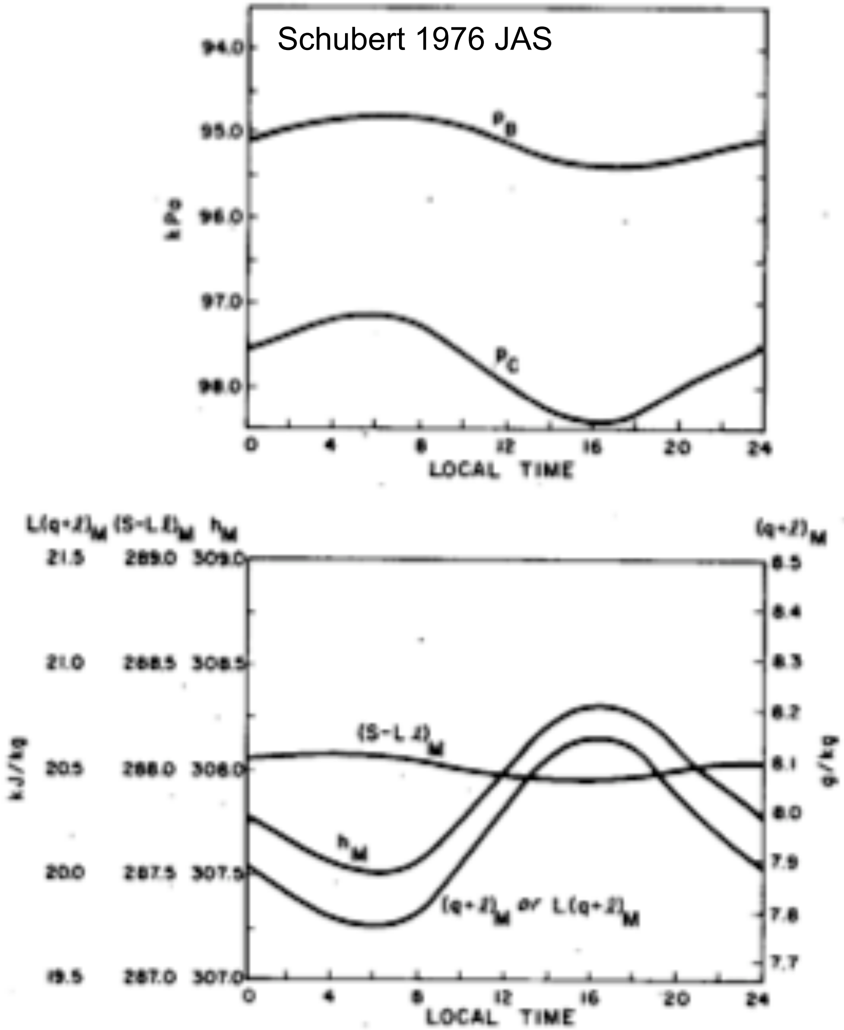


Fig. 7a. Diurnal variation of p_B and p_c (top) and h_M, $(s-Ll)_M$ and $(q+l)_M$ (bottom). Local time 1200 corresponds to noon. The large-scale divergence is 5.0×10^{-6} s^{-1}, the sea surface temperature 13°C, and the entrainment parameter 0.20.

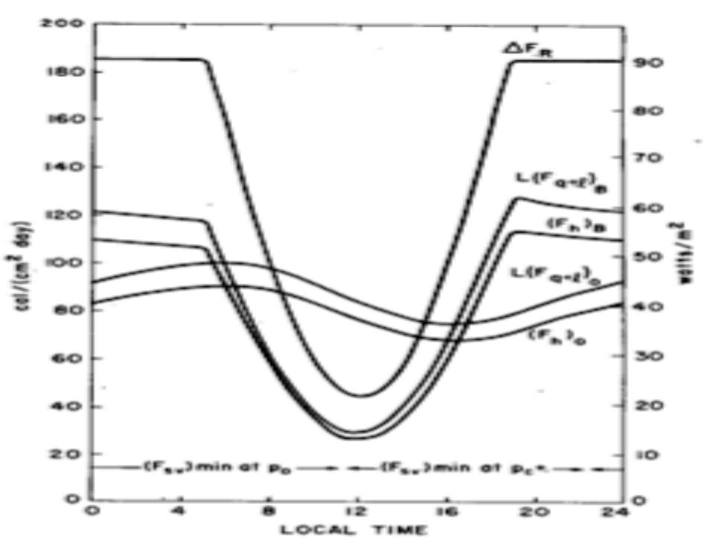
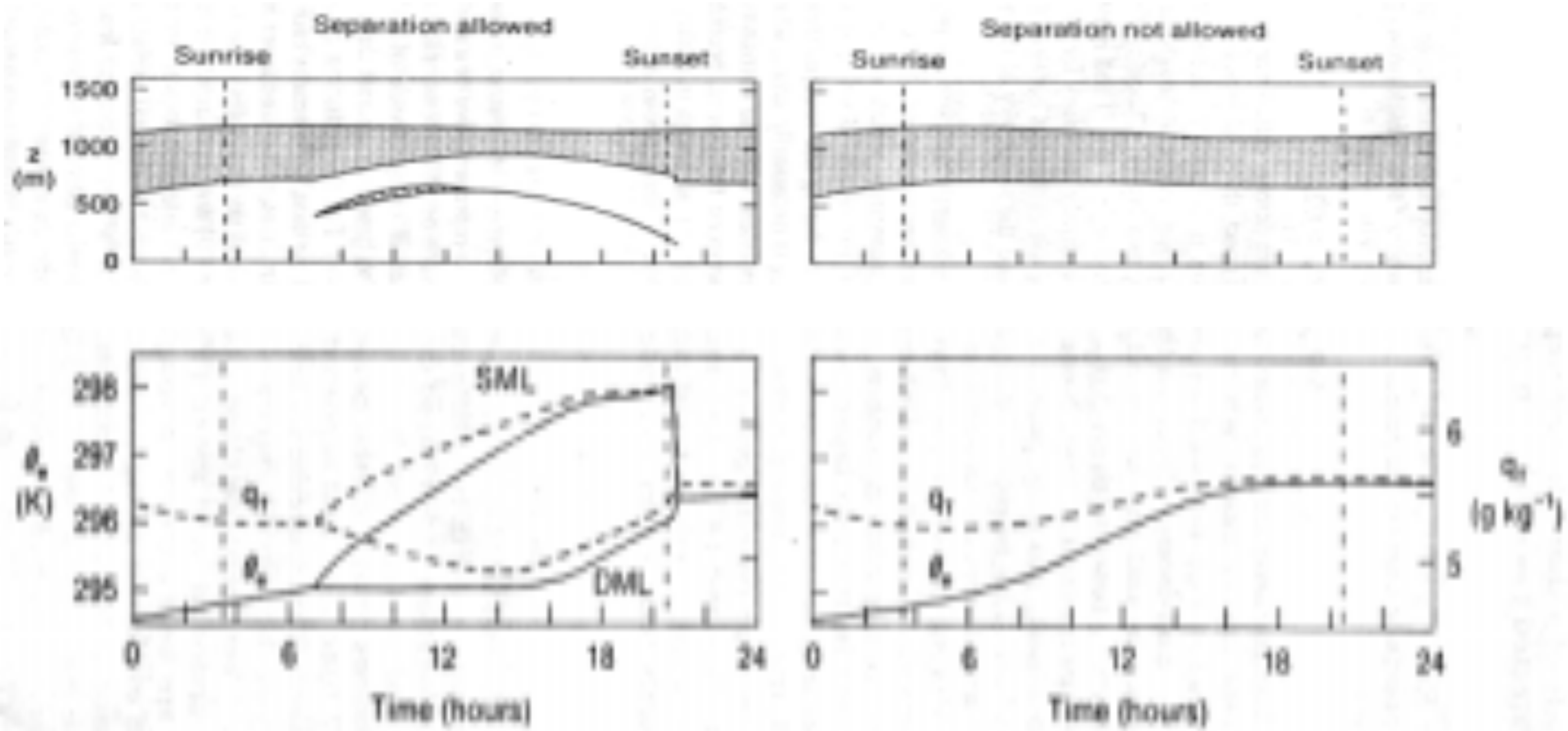


Fig. 7b. Diurnal variation of ΔF_R [see Eq. (27)], $(F_h)_B$, $(F_h)_c$, $L(F_{q+l})_B$ and $L(F_{q+l})_c$.

Multiple mixed layer model



Turton and Nicholls 1987 QJ