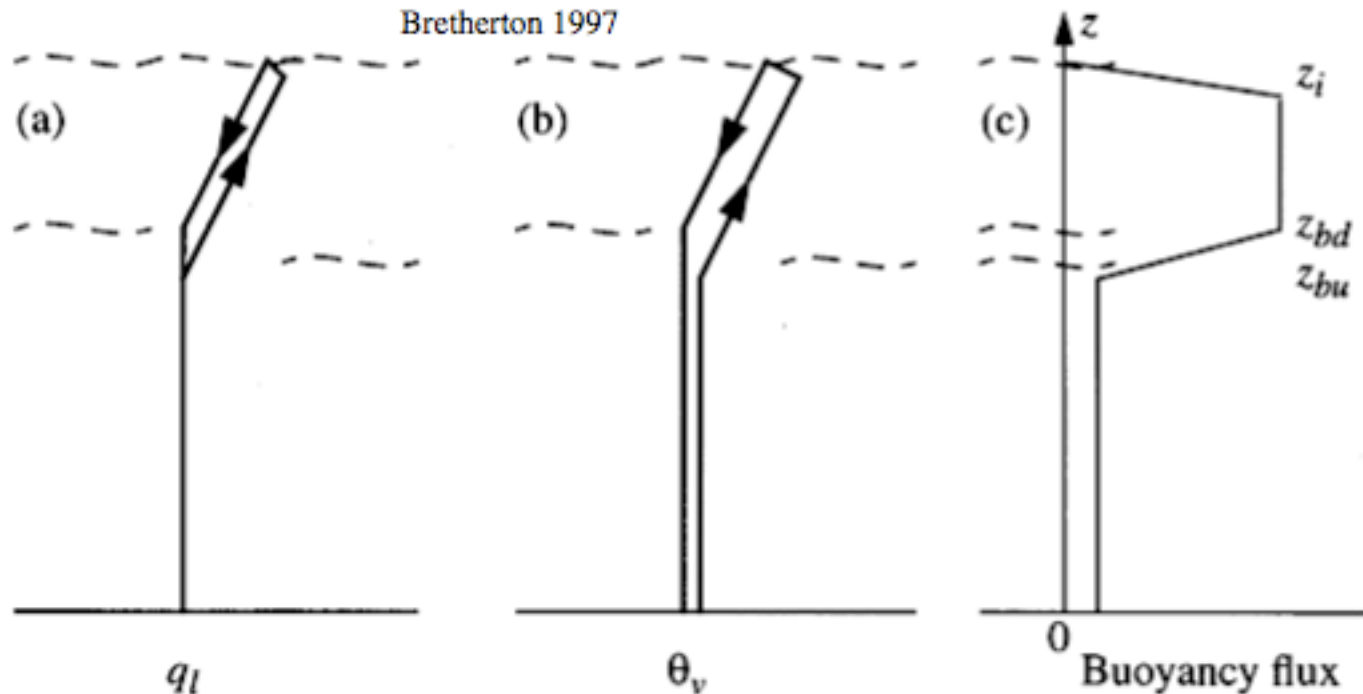


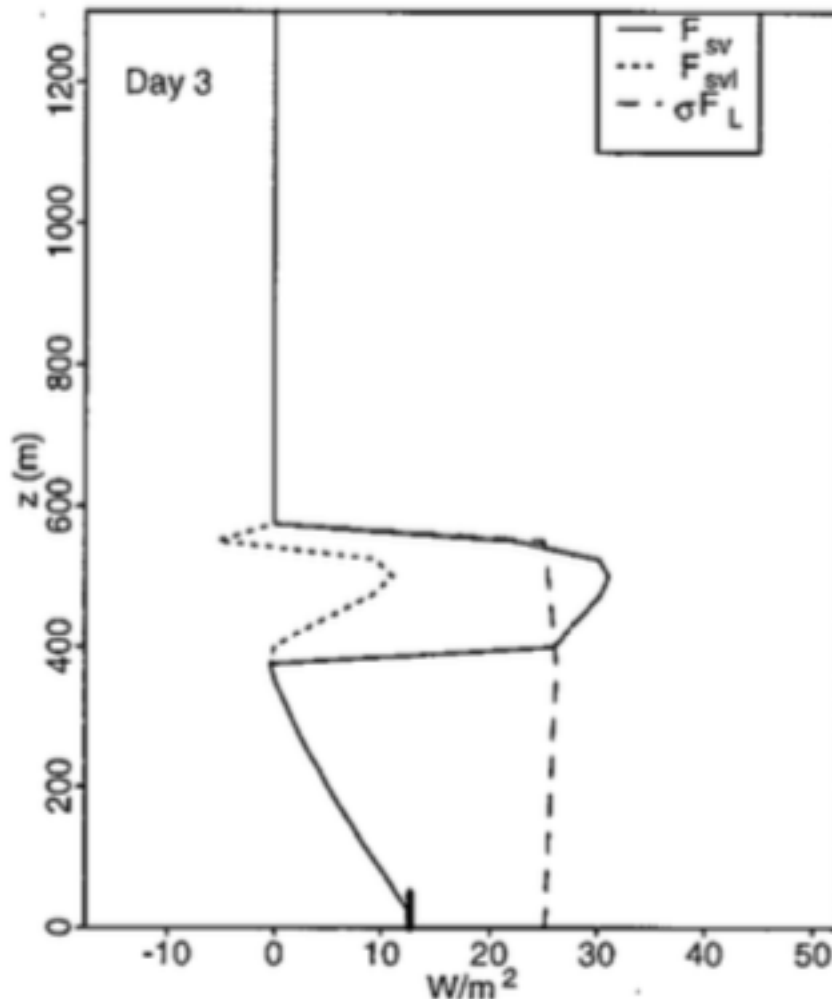
Parcel circuits in a Sc-capped mixed layer



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

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

Buoyancy flux profile in a Sc-capped mixed layer



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 $\sigma \sim 0.35$.

Bretherton and Wyant 1997, Fig. 4

Sc MLM entrainment closure

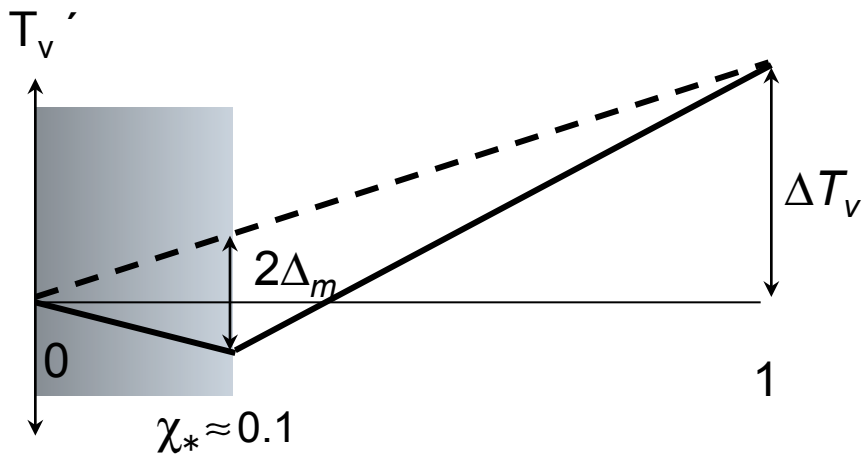
Nicholls-Turton (1986) entrainment closure
Fit to aircraft and lab obs and dry CBL

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

Evaporative enhancement: Less buoyant mixtures easier to entrain.

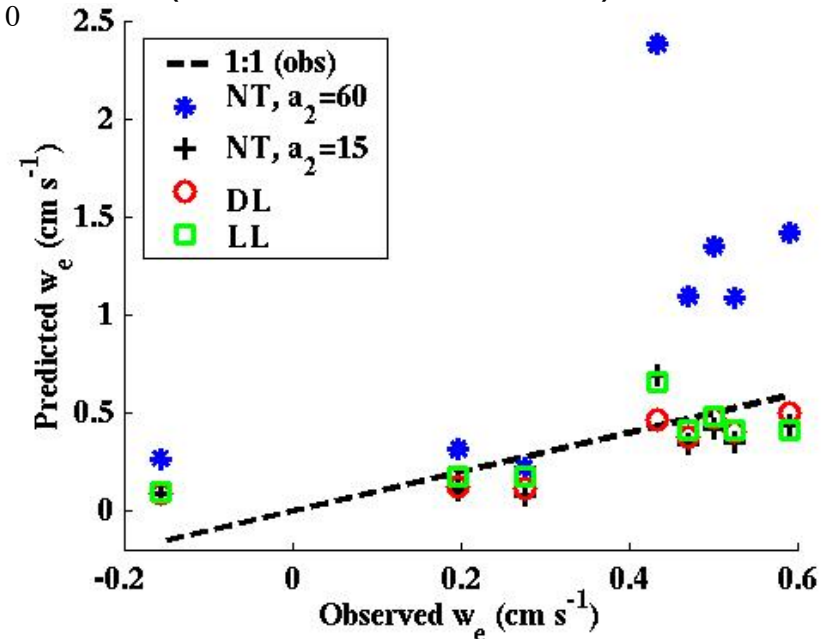
NT enhancement factor $E = \Delta_m / \Delta T_v$

$a_2 = 15-60 \rightarrow A = 0.5 - 5$ in typical Sc



Entrained fraction χ

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

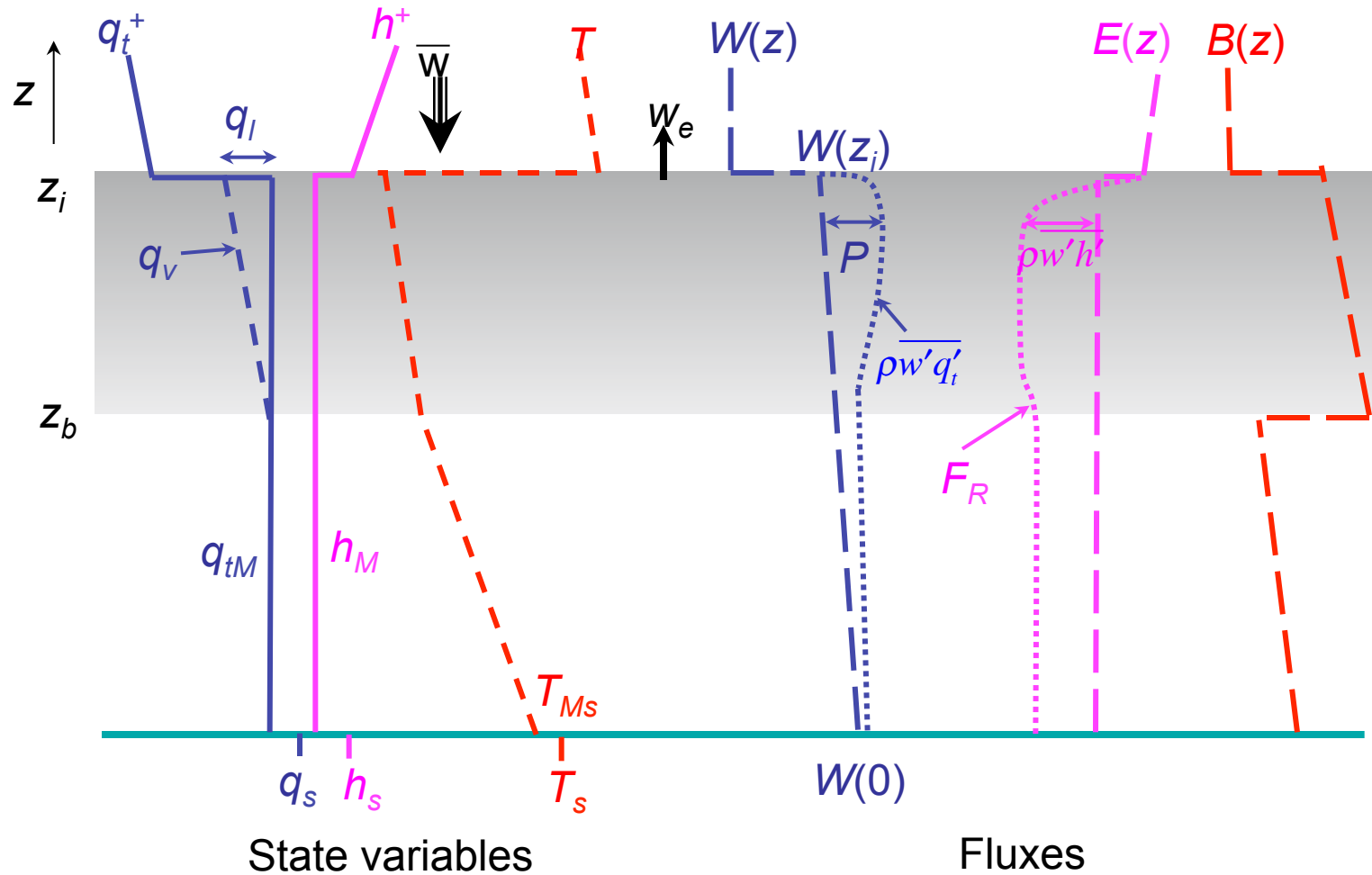


NT: Nicholls and Turton (1986)

DL: Lilly (2002)

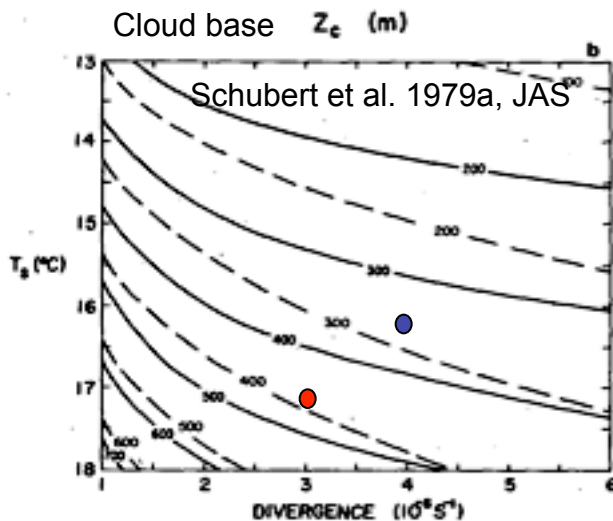
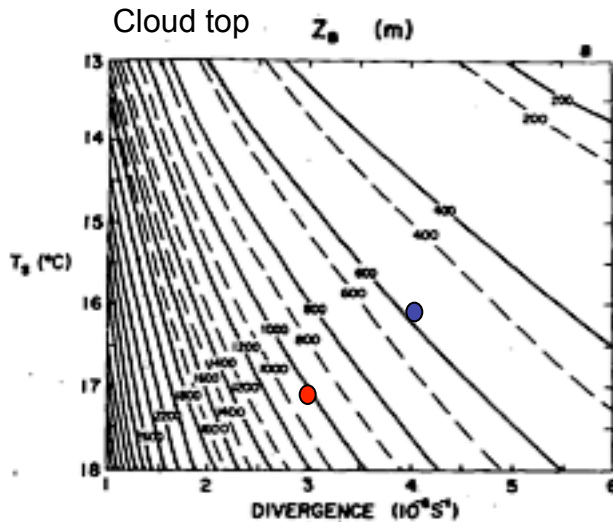
LL: Lewellen&Lewellen (2003)

Profiles in a stratocumulus-capped mixed layer

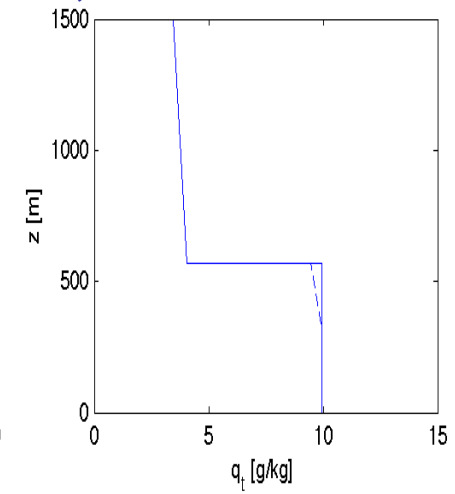
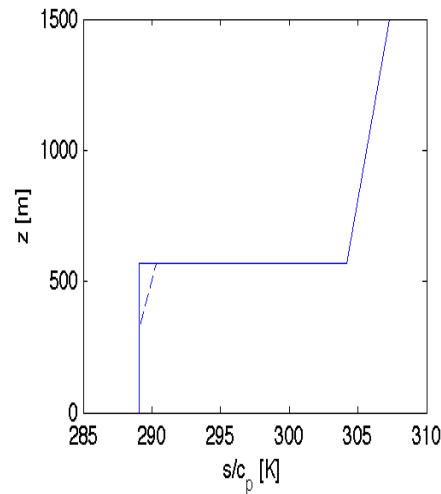


MLM examples

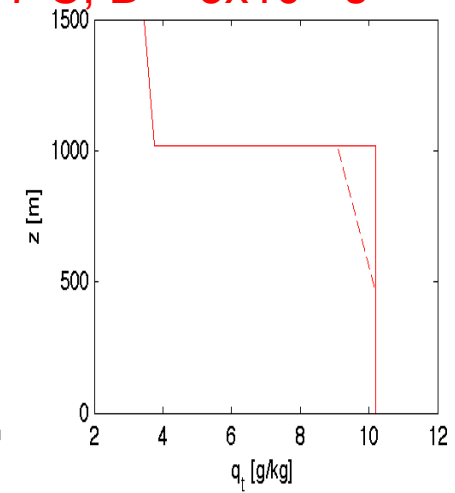
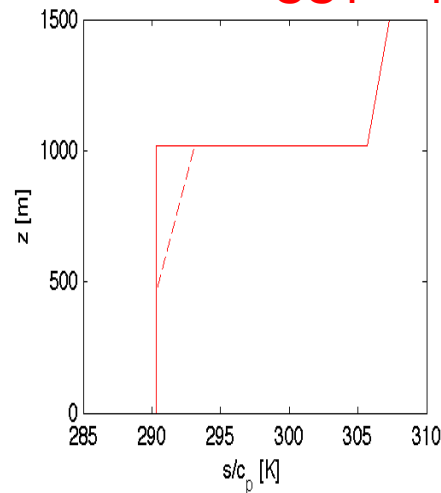
Steady-state solutions: Higher SST, lower divergence promote deeper mixed layer with thicker cloud.



SST = 16 C, $D = 4 \times 10^{-6} s^{-1}$



SST = 17 C, $D = 3 \times 10^{-6} s^{-1}$



MLM response to a +2K SST jump

Two timescales:

Fast internal adjustment

$$t_b = z_i / C_T V \sim 0.5 \text{ day}$$

Slow inversion adjustment

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

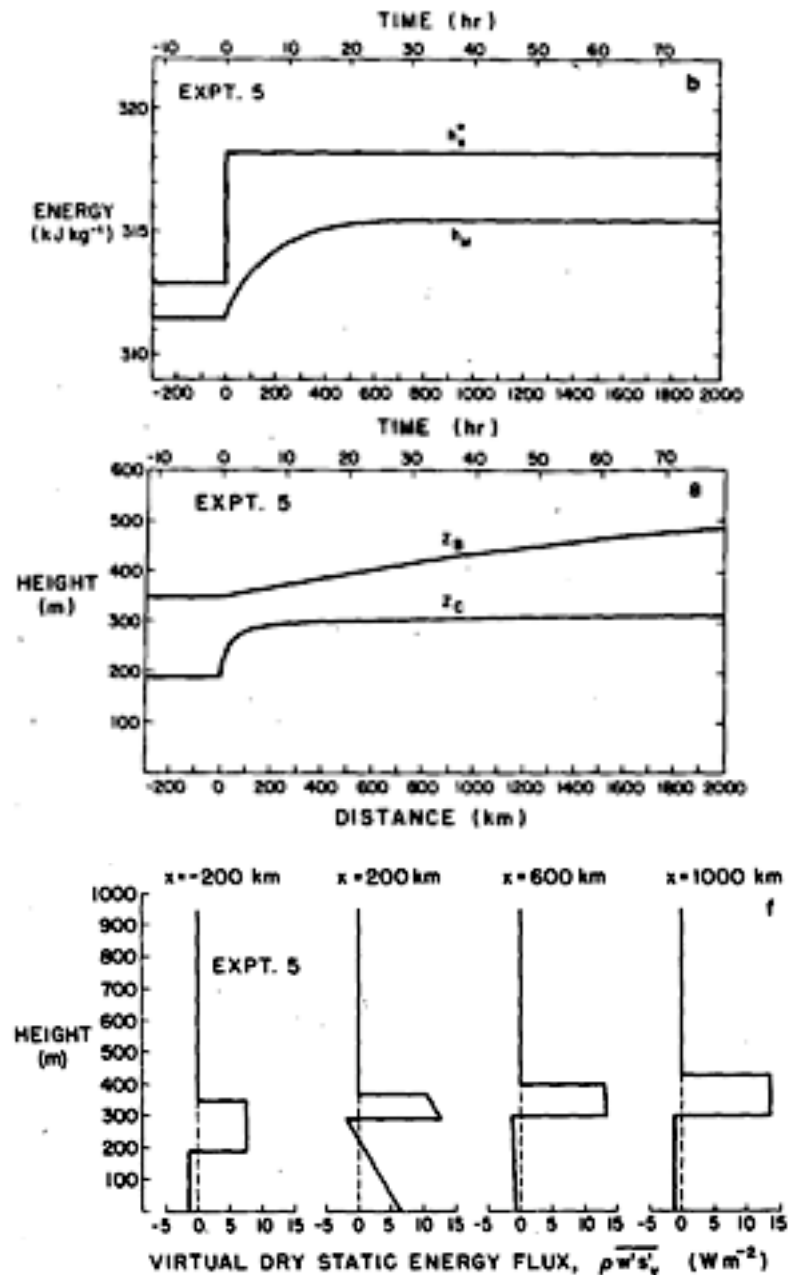
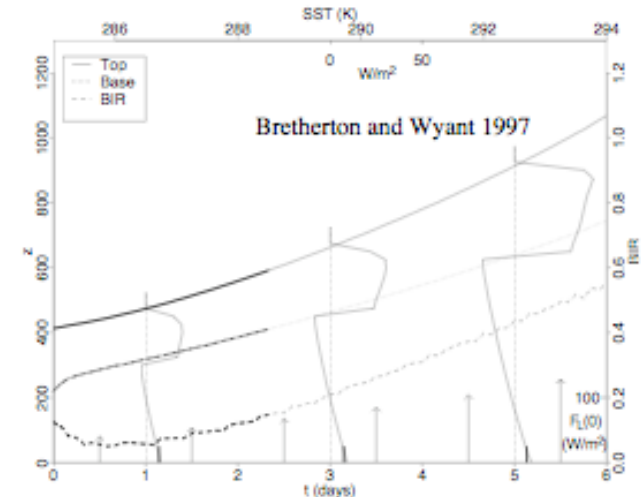


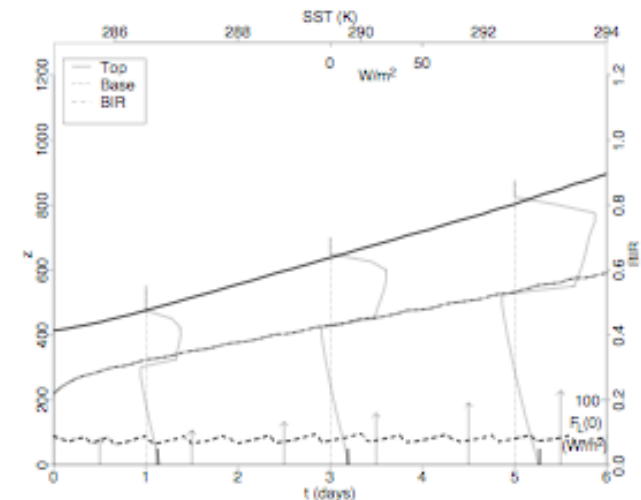
FIG. 11. Results for Experiment 5 (constant divergence, instantaneous 2°C increase in sea surface temperature).

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.

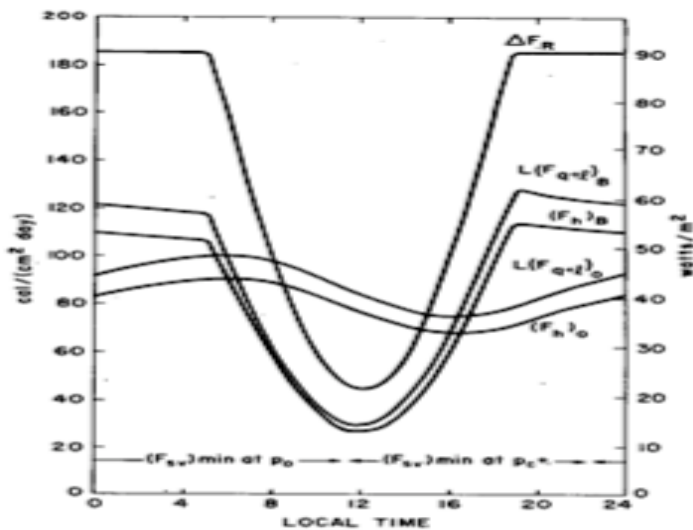


FIG. 7b. Diurnal variation of ΔF_R [see Eq. (27)], $(F_{s+2})_B$, $(F_{s+2})_0$, $L(F_{q+2})_B$ and $L(F_{q+2})_0$.

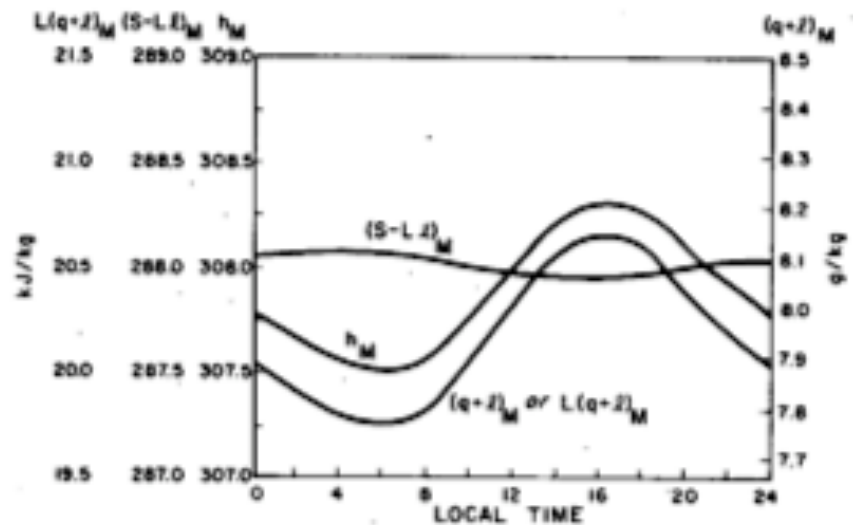
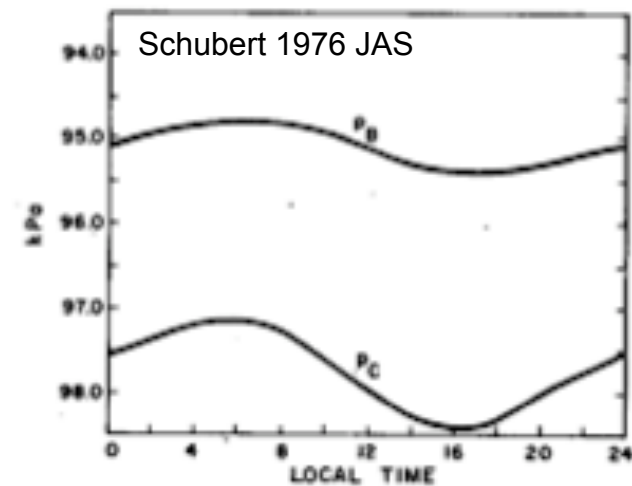
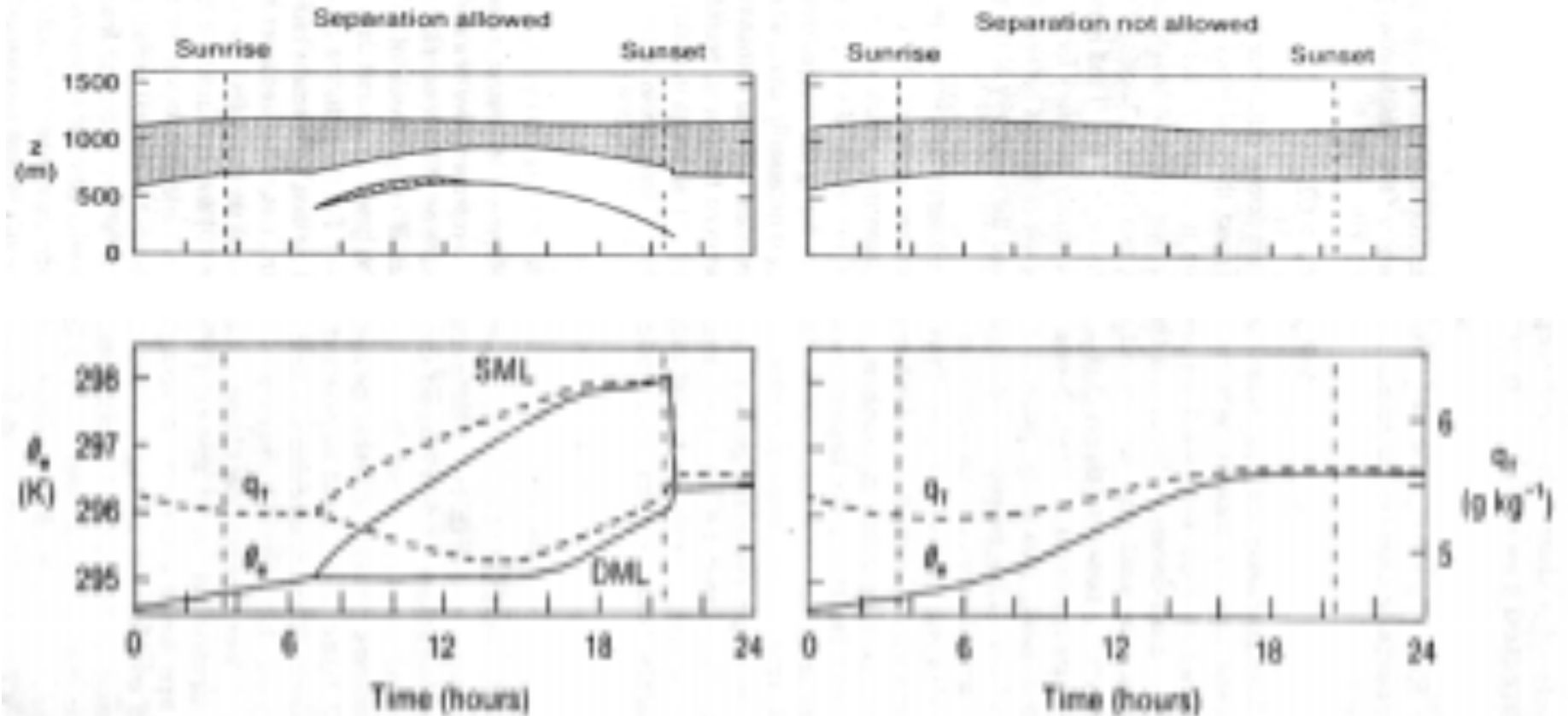


FIG. 7a. Diurnal variation of p_B and p_c (top) and h_M , $(s-L)_M$ and $(q+2)_M$ (bottom). Local time 1200 corresponds to noon. The large-scale divergence is $5.0 \times 10^{-6} \text{ s}^{-1}$, the sea surface temperature 13°C , and the entrainment parameter 0.20.

Multiple mixed layer model



Turton and Nicholls 1987 QJ