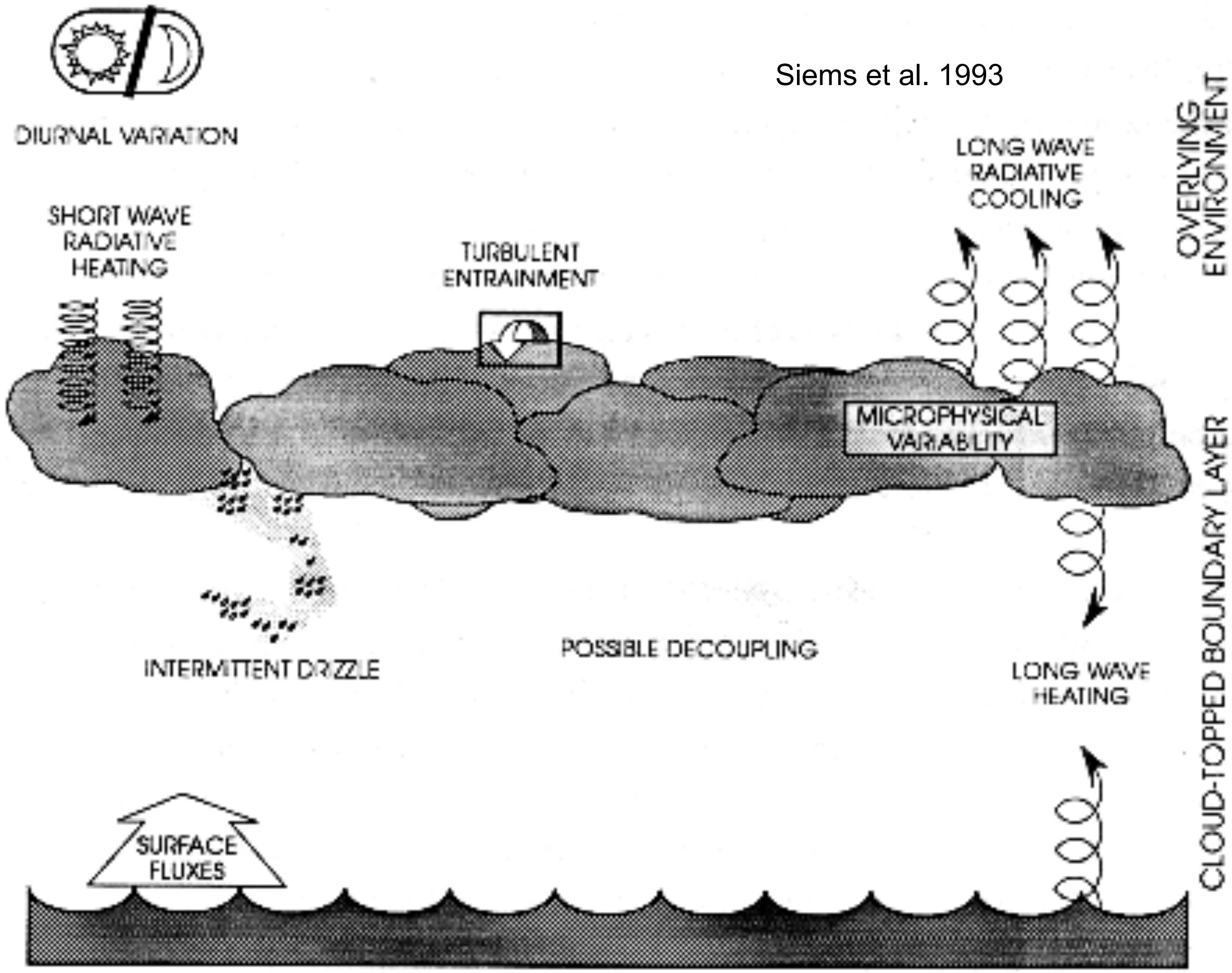
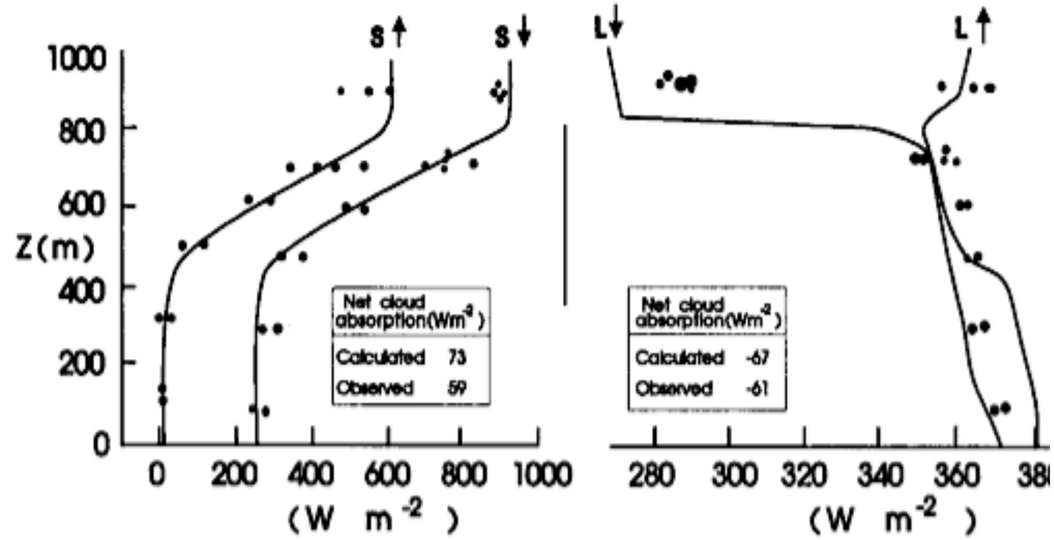
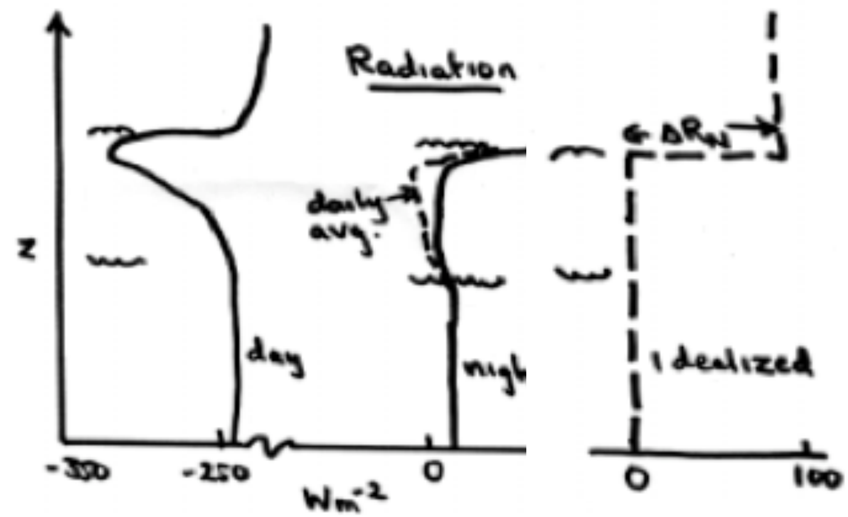
# Physical processes affecting stratocumulus



# Sc physical processes: Radiation




Radiative fluxes in North Sea stratocumulus (Nicholls 1984)

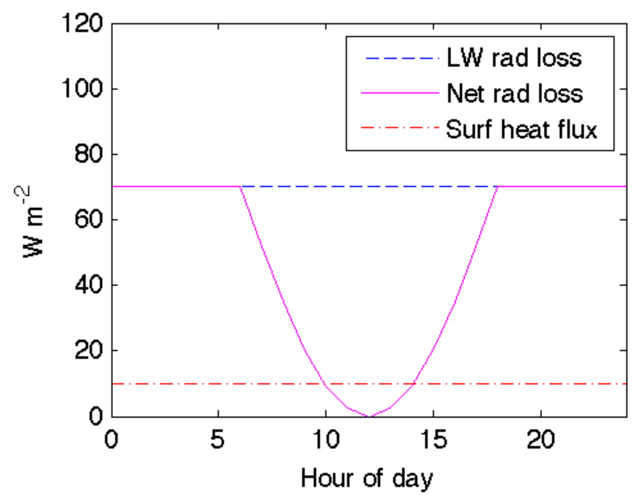



Net upward radiative flux

Strong longwave cooling at cloud top destabilizes SCBL, creating turbulence

Shortwave heating in cloud cancels much of the longwave cooling during the day, weakening turbulence and favoring decoupling.

Subtropical CBL radiative energy loss is usually large compared to surface heat flux.




Diurnal cycle of net SCBL rad cooling

# Profiles in a stratocumulus-capped mixed layer

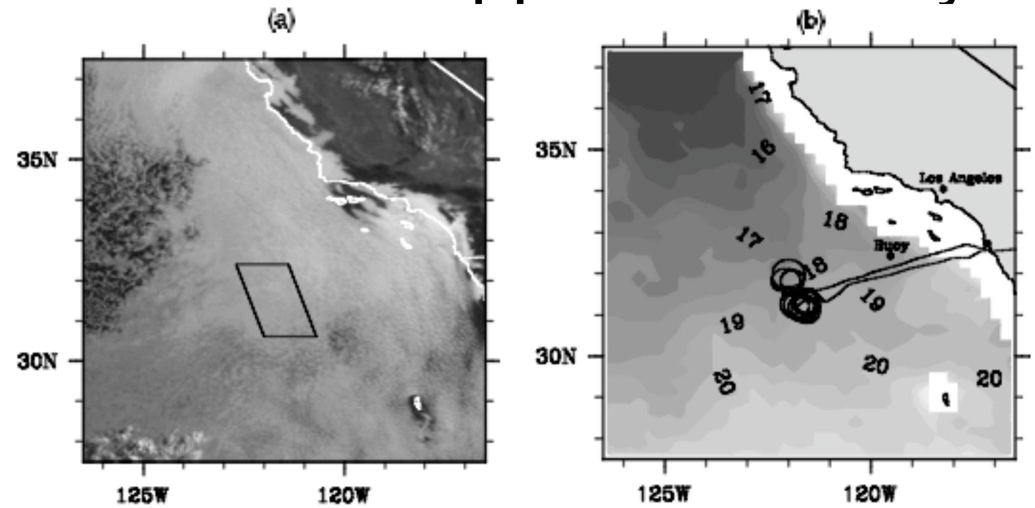
'Well-mixed' : Moist-conserved variables

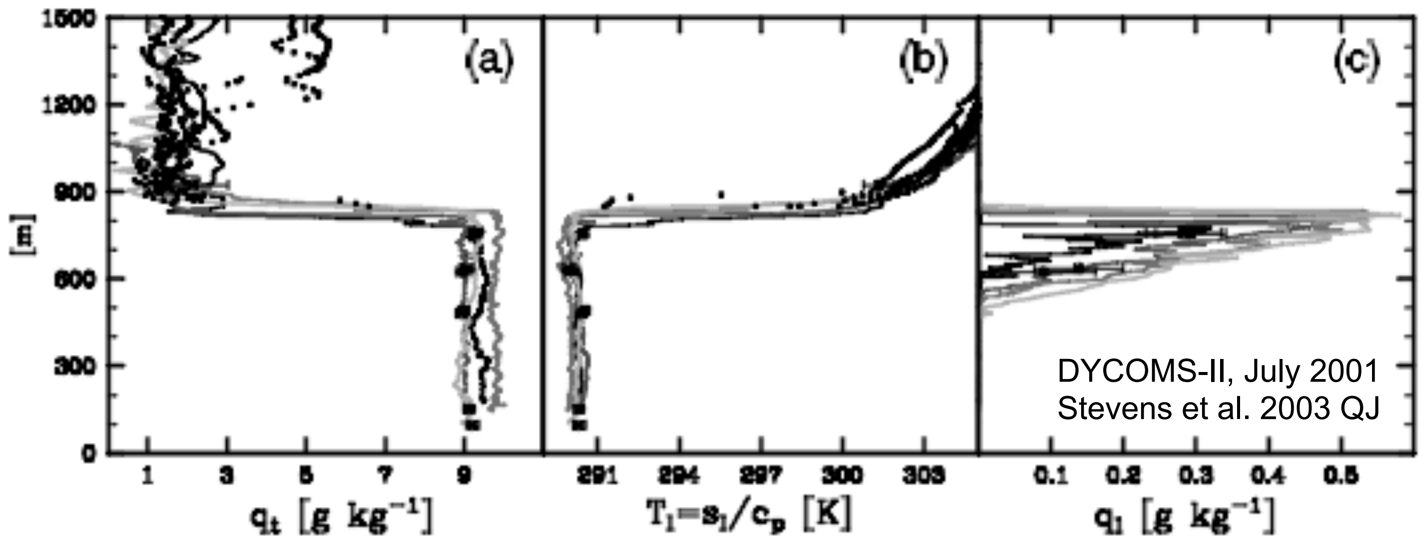
$s_l = c_pT + gz - Lq_l$,

$q_t = q_v + q_l$

$h = c_pT + gz + Lq_t$

are nearly uniform with height within the MBL.

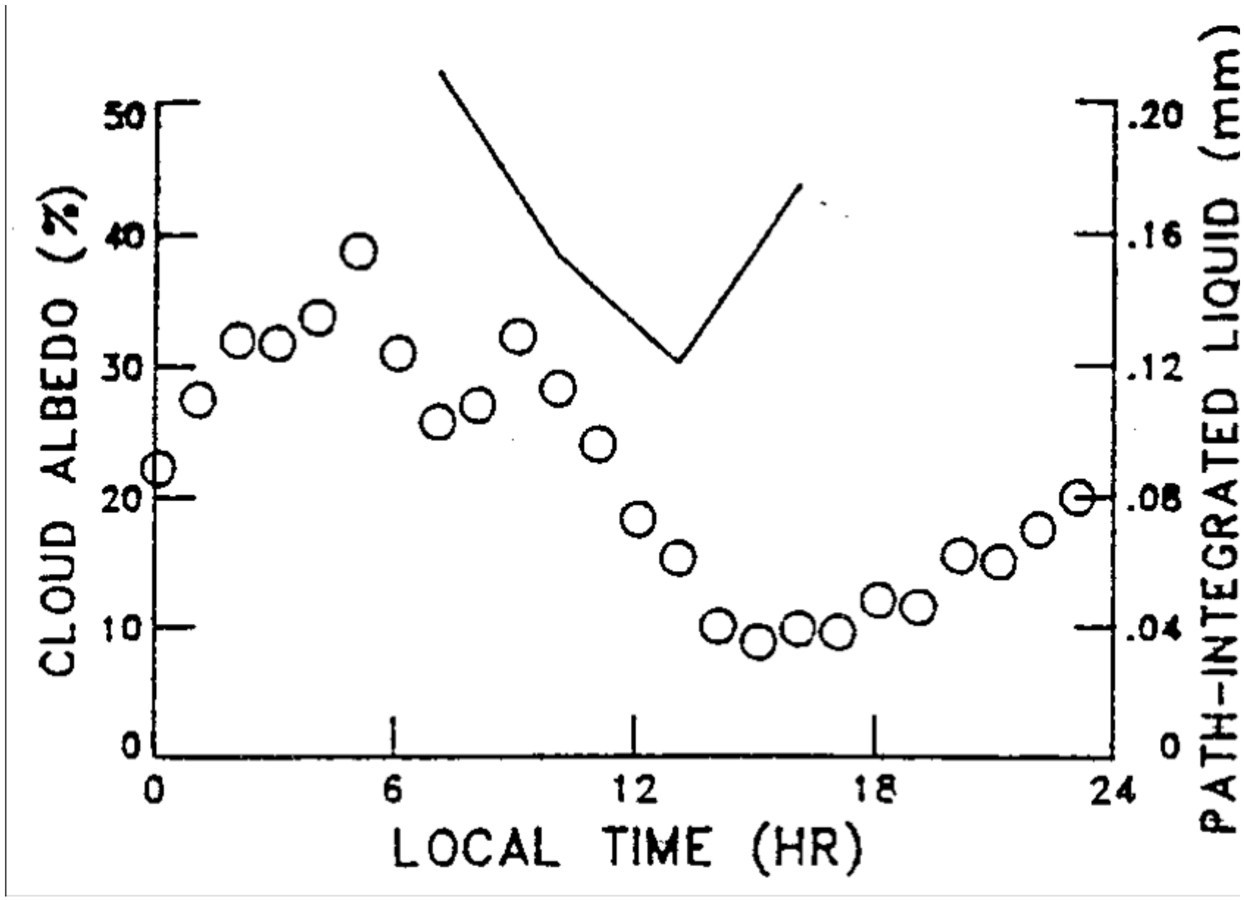



$q_l$ increases linearly with z above cloud base

Figure 1. Cloud-layer state as observed during RF01: (a) total-water specific humidity $q_t$, (b) liquid-water static energy temperature $s_l/c_p$, and (c) liquid-water specific humidity $q_l$. Lines are from soundings, darker indicating earlier, filled circles and bars denote level-leg means and standard deviations, and dots denote dropsonde data from the above-cloud portion of the descent.

# Sc diurnal cycle of liquid water path and albedo




The diurnal cycle of cloud albedo (solid) and liquid water path (circles) averaged over 23 Jun - 15 Jul 1987 at San Nicholas Island off the California coast during the FIRE-MSC experiment.

# Decoupled SCBL - midday, North Atlantic.

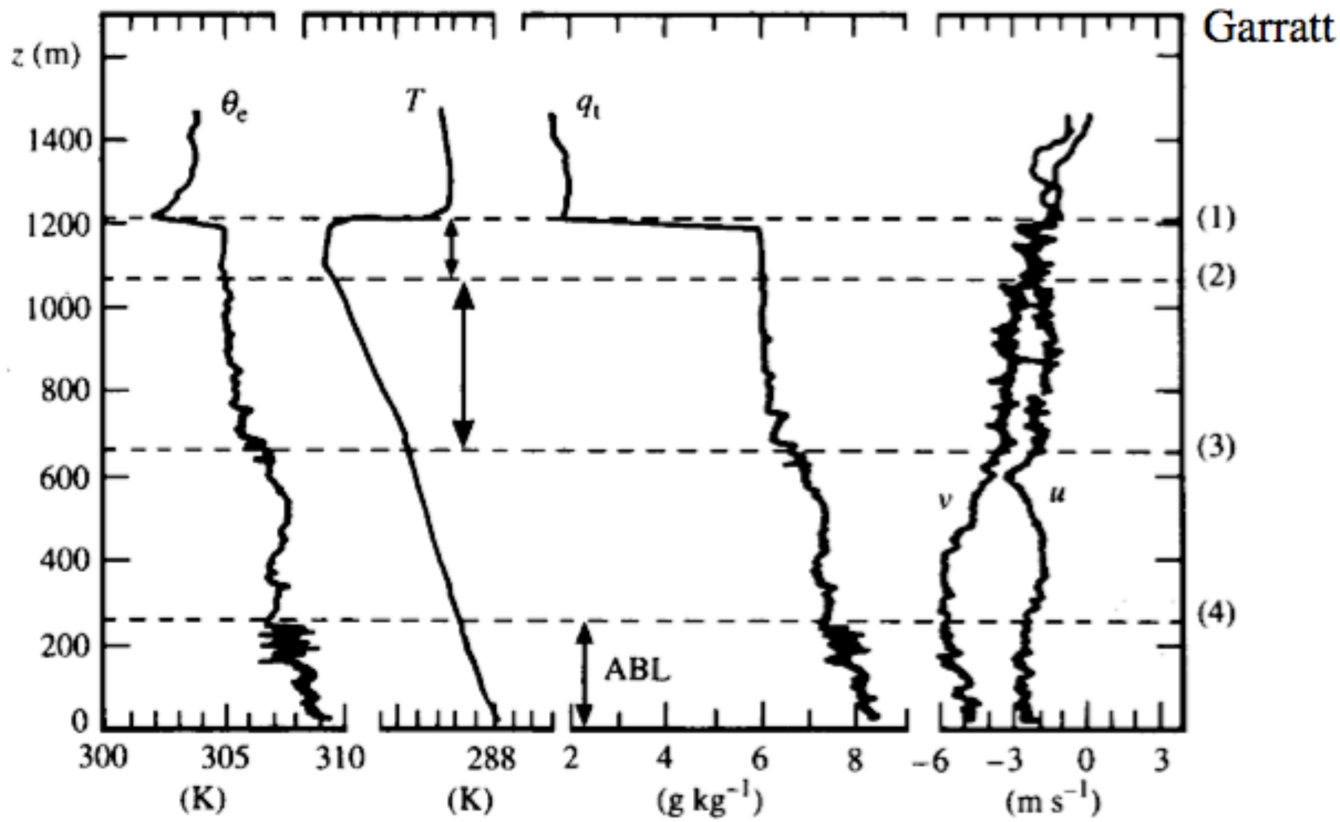
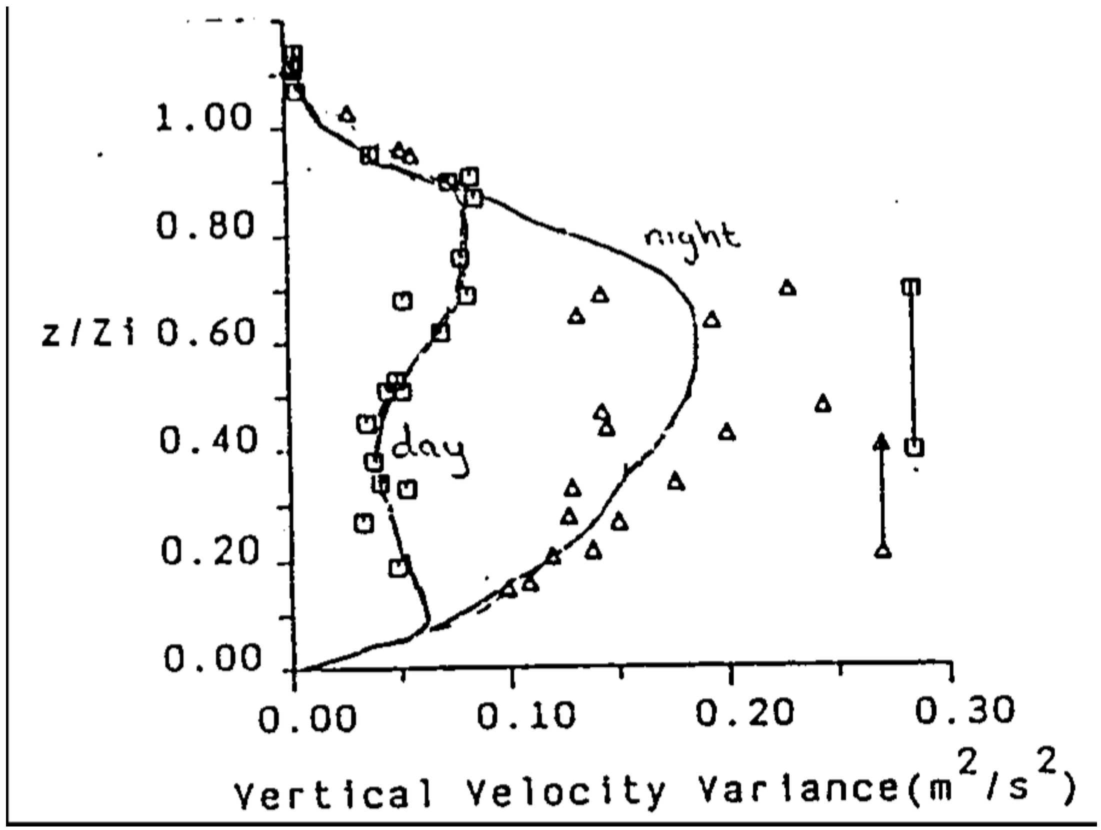


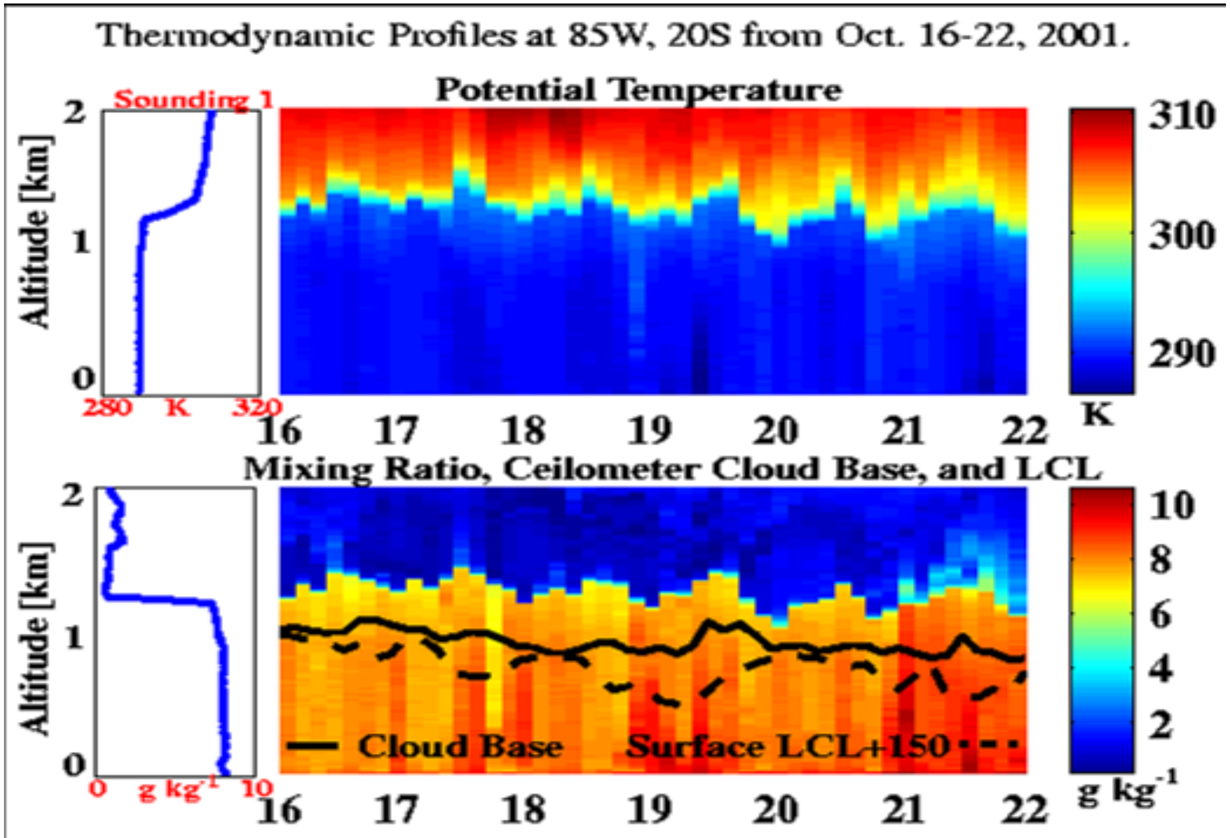

Fig. 7.5 Observed mean profiles of thermodynamic variables and wind components made in the CTBL over the ocean during JASIN, for a decoupled stratocumulus layer. The pecked horizontal lines delineate layer boundaries as follows: (1) cloud top; (2) cloud base; (3) bottom of subcloud layer; (4) top of the surface-related Ekman layer. After Nicholls and Leighton (1986), *Quarterly Journal of the Royal Meteorological Society*.

# Day vs. night profiles of turbulence in Sc-topped BL




Mean daytime and nighttime vertical velocity variance profiles measured by a tethered balloon in June 1987 at San Nicolas Island off the CA coast during FIRE-MSC (Hignett 1991) .

# SCBL diurnal cycle in SE Pacific sonde time series




(Bretherton et al. 2004)

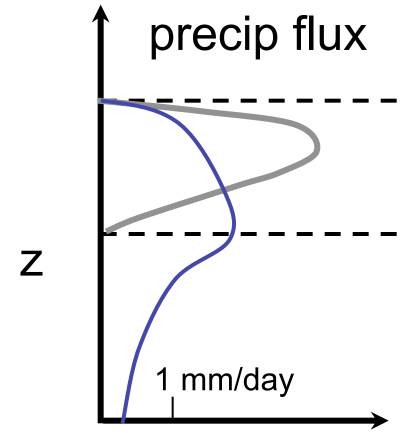
3-hourly sondes show:

1. Mixed-layer structure with strong sharp inversion
2. Regular night-time increase in inversion height, cloud thickness.
3. Decoupling measured by cloud base - LCL increases during daytime and during periods of drizzle on 19, 21 Oct. (local noon = 18 UTC)

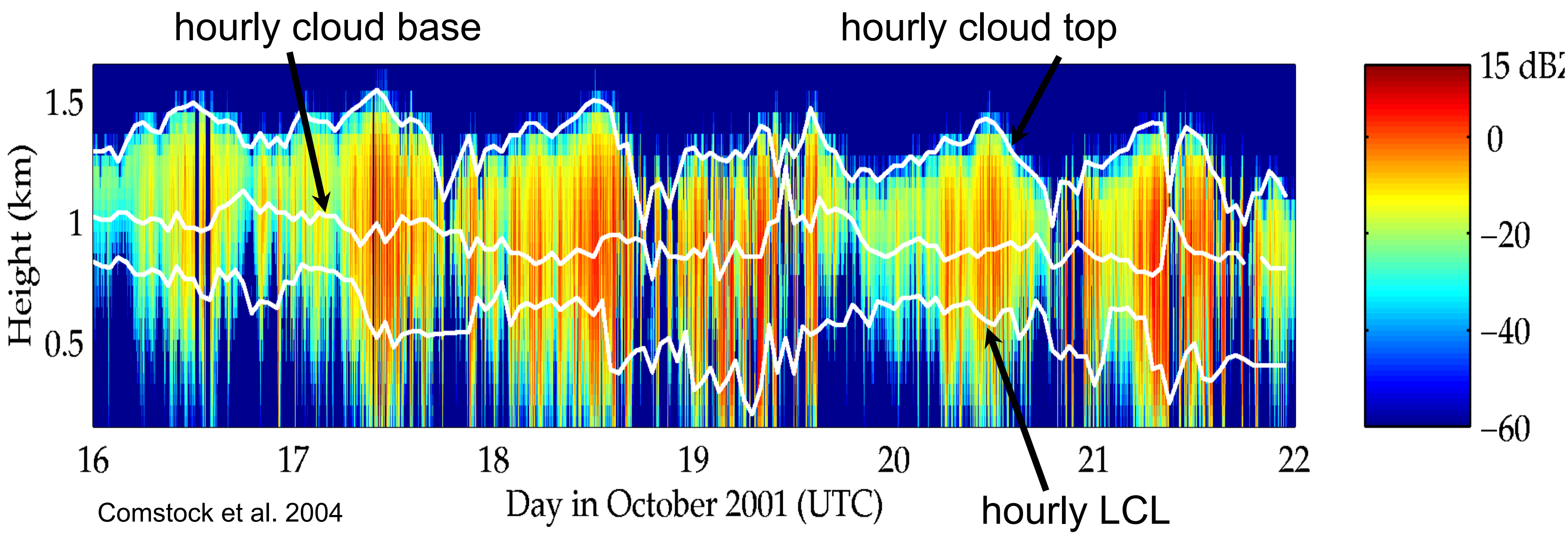
# Sc physical processes: Precipitation

Drizzle: Drops > 100 μm radius, falling ~ 1 m s$^{-1}$.

Sedimentation (in cloud only): Cloud droplets less than 20 μm radius, falling a few cm s$^{-1}$.



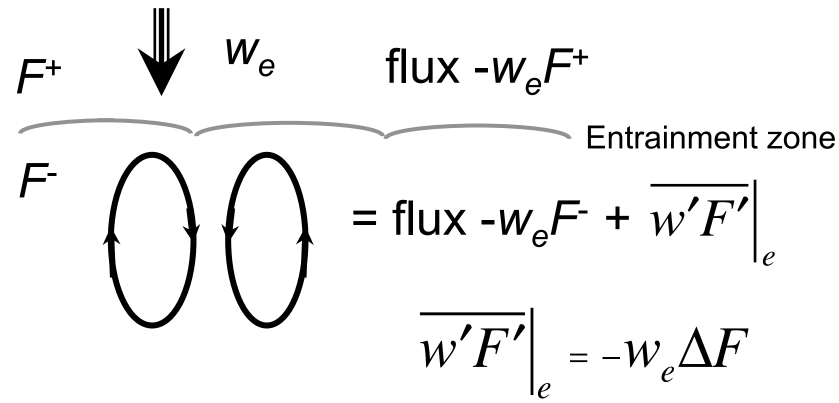

EPIC 8-mm vertically pointing 'cloud radar' observations of drizzling Sc




Comstock et al. 2004

# Sc physical processes: Turbulent entrainment

- Driven by turbulence
- Inhibited by a strong inversion
- Must be measured indirectly (flux-jump or budget residual methods)




DYCOMS-II RF01 (Stevens et al. 2003):
Flight thru nocturnal Sc-capped mixed layer

$$\Delta q_t = 7.5 \pm 0.5 \text{ g kg}^{-1},$$

$$\Delta \text{DMS} = -60.2 \pm 4.5 \text{ pptv},$$

$$\Delta \text{O}_3 = 23 \pm 4.3 \text{ ppbv}$$

TABLE 2. ENTRAINMENT VELOCITY ESTIMATES

| Method | Estimate (cm $s^{-1}$) |
|---|---|
| $q_t$ budget | $0.34 \pm 0.11$ |
| $s_l$ budget | $0.46 \pm 0.08$ |
| $q_t$ cloud-top flux | $0.37 \pm 0.06$ |
| $O_3$ cloud-top flux | $0.27 \pm 0.09$ |
| DMS cloud-top flux | $0.53 \pm 0.11$ |
| Weighted average | $0.39 \pm 0.04$ |

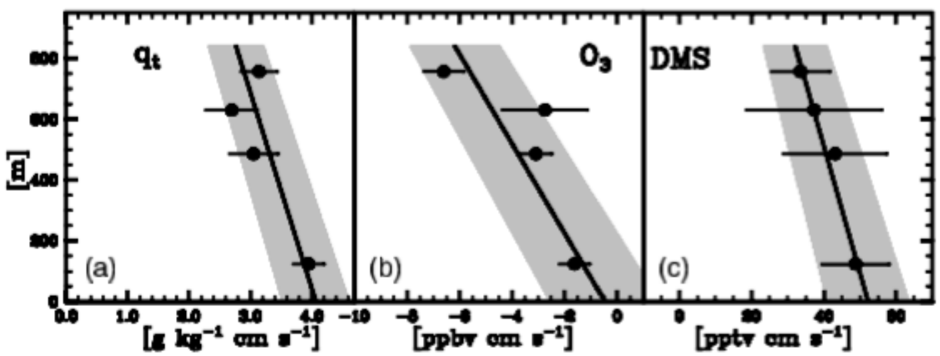


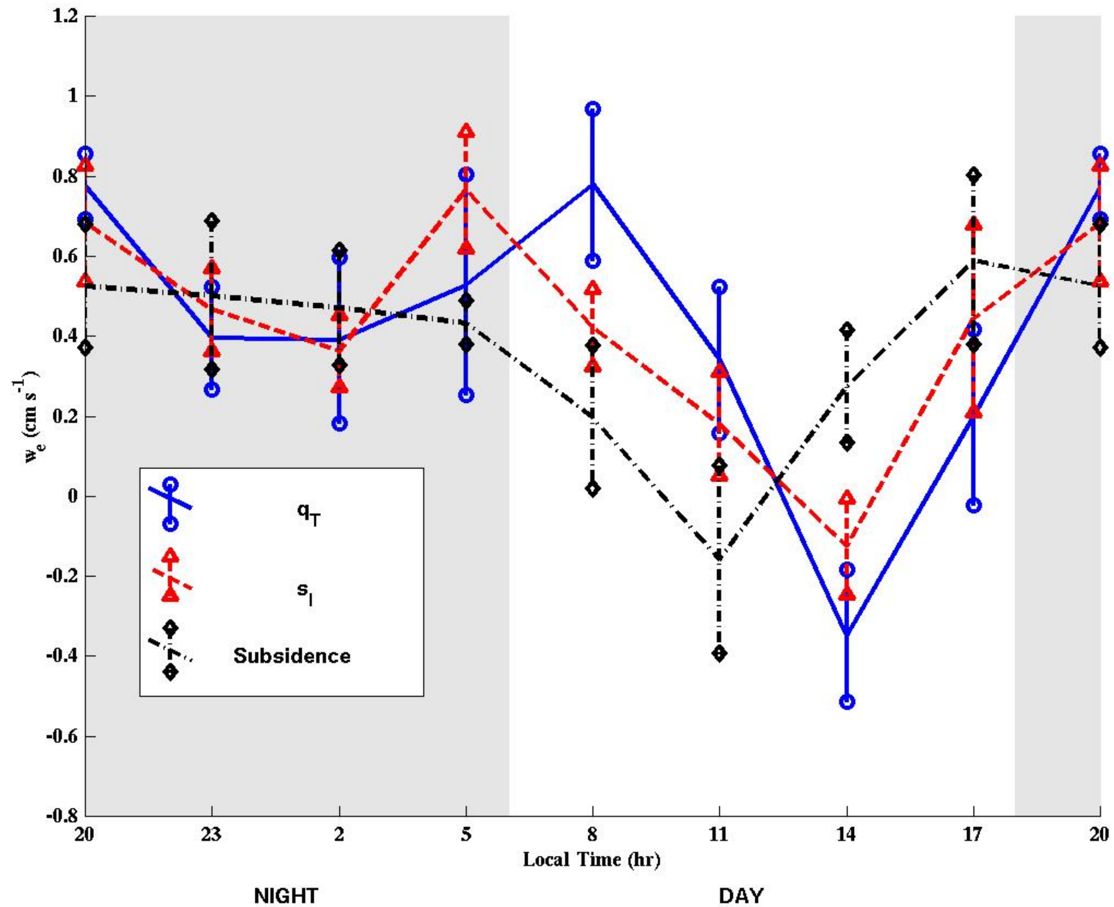

Figure 8. Flux versus height and weighted least-squared linear fit, with uncertainty shaded, for (a) $q_t$, (b) $O_3$, and (c) DMS (see text).

# Budget residual method for estimating entrainment from ship obs

A 6-day composite diurnal cycle of entrainment rate by SE Pacific Sc during EPIC 2001 (right) based on SCBL mass (black), moisture (blue) and heat budgets (red).

All three estimates are qualitatively consistent, with strongest entrainment at night and typical magnitudes of 0-8 mm/s, but measurement uncertainties are large.

Needed terms in the budget equations were deduced from radiosondes and ship-based observations of surface precipitation, radiative and turbulent fluxes. ECMWF vertical motion was used in the mass budget and a clear-sky radiation calculation was used above the cloud layer.




Caldwell and Bretherton 2005