Critical aspects of cloudy boundary layers: what do we need to know?

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Intermodel SW feedback variability determined by low cloud changes

Key physical processes in the cloudy boundary layer

- Evaporative cooling
- Latent heating
- Turbulent mixing
- Longwave cooling
- Solar heating
- Drizzle
- Entrainment
- Surface fluxes energy & moisture

0.5-2 km
Stratocumulus,
NE Pacific, July 2001

Trade cumuli,
Antigua, Jan 2005

Photograph: Bjorn Stevens
Varying cloudy PBL structure
Mesoscale cellular structure

(a) Radiative cooling → Entrainment → VERY DRY
   → Weak surface forcing
   → Drizzle below thickest cloud

Shallow MBL

Sea surface

800 m

5 km

(b) Locally enhanced entrainment → VERY DRY
   → TRADE inversion
   → QUIESCENT
   → TURBOULENT
   → MOIST
   → LCL

Deep MBL

1.5 km

20-30 km
GPS R-O observations of MBL depth

COSMIC (2006-2009), annual mean MBL depth
Cloud thickness of stratiform boundary layer clouds

MODIS cloud LWP, and cloud temperature, used to determine adiabatic h

PBL Clouds are thin!
Many MBL clouds have low LWP

Reflectivity in $[LWP, N_d]$ space

Increasing relative importance of $LWP$ over $N_d$ at high rainrates

Wood, Kubar and Hartmann (2009)
Cloud droplet concentration *estimates* from MODIS

Use MODIS optical depth and effective radius to infer droplet concentration assuming adiabatic clouds.
Turbulence and entrainment

Cloud top and entrainment
Effect of changing entrainment efficiency

Entrainment critical for correct prediction of cloud LWP and therefore optical thickness

Stevens (2002)
Key considerations for spaceborne observations of PBL cloud structure

- Cloudy boundary layer almost everywhere **shallower than 2 km**, often as shallow as few hundred meters
- PBL clouds typically **200-500 m thick**
- Drizzle **very sensitive to small changes in LWP/cloud thickness**, and to **cloud droplet concentration**
- **Low liquid water path**, scant/no information from space on vertical profile of LWP
- Need information on turbulence structure and **entrainment**
Sensor synergy – MBL profile reconstruction

**Inputs:**
MODIS LWP => cloud thickness, cloud top temperature pdf
AMSR => SST, column WVP
GPS => FT moisture, MBL depth
AMSR-GPS => MBL moisture path

**Outputs:**
MBL moisture/temp stratification
Inversion structure (trade wind MBL)
Lapse rate (static stability in the MBL)
Entrainment rate estimates

Wood and Bretherton et al. (J Climate, 2004)
Supplementary slides
Cloud feedbacks remain the leading source of uncertainty in future climate prediction

From Bony et al. (2006)
Condensational Growth to grow cloud droplets (Nonprecipitating cloud)

Collision and Coalescence to grow into drizzle and rain drops

Cloud Condensation Nuclei (CCN) $d \approx 0.1 \mu m$

$\text{d} \approx 50 \mu m$

$\text{d} \approx 20 \mu m$

$\text{d} \approx 200 \mu m$ (drizzle)

$\text{d} \approx 1 \text{ mm}$ (large drizzle drop or even rain drop)
Tight couplings between SST, winds, and clouds
MBL depth/cloud top height estimates
POCKETS of OPEN CELLS (POCs)
MBL depth, LWP, and POC formation
With independent cloud top height or MBL depth information

- Lapse rate (MODIS CTT, CALIPSO CTH, SST)

Wu et al. (GRSL, 2008)